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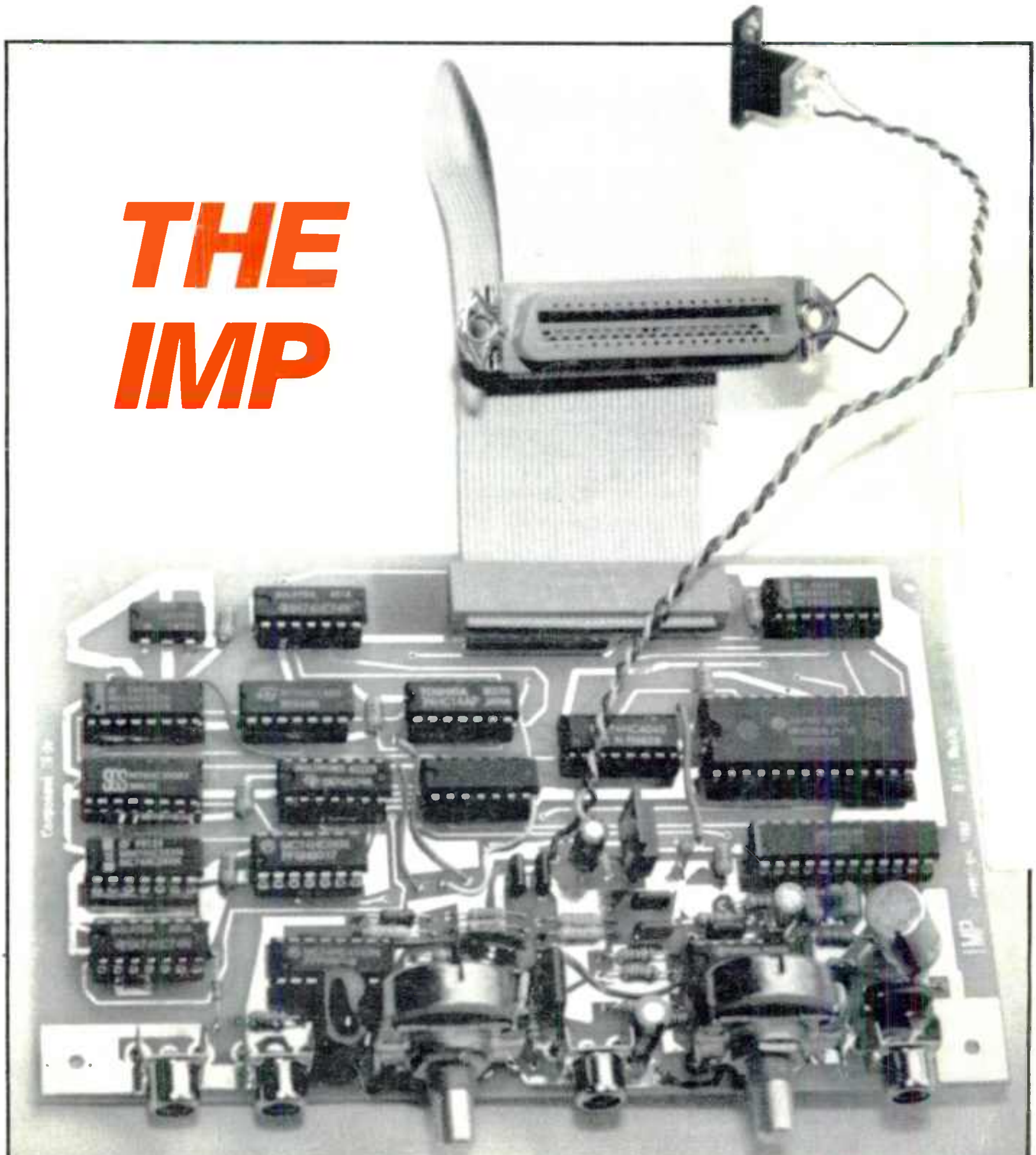
SpeakerBuilder
THE LOUDSPEAKER JOURNAL

THE IMP



Good News

Due to customer interest, **PEERLESS OF AMERICA, INC.** has produced a 12″ woofer which combines a 1.3kg magnet with a 22mm-long, four layer voice coil, as is used in the company's 10″ CC woofer. The new unit has a short-circuiting ring in the magnet system to reduce distortion, as well as a new rubber surround to improve the restoring force linearity over a longer stroke. It is suitable for applications in closed box or reflex systems of 60–100 liters or, if an extra deep bass is required, larger reflex boxes; it may also be used in normal three-way systems with a crossover of 500–800Hz.

Inquiries may be directed to Peerless of America, Inc., 800 W. Central Rd., Mt. Prospect, IL 60056, (708) 394-9678, FAX (708) 392-8099.

Reader Service #64

DECADE ENGINEERING's Decade 1000 Electronic Crossover Kit allows for bi-amping of car or home stereo systems by splitting low and high frequencies for separate power amplifiers. Builders can also cascade individual filters or entire assemblies to create sharp filter response, or construct a tri-amp system with two kits. Modification converts the audio filter into a bass equalizer or subwoofer crossover.

Decade also has a new line of electronics kits, including a digital voice scrambler/descrambler, a two-digit voltmeter, a versatile electronic crossover/bass equalizer, and an oil-contamination meter. Each kit contains complete assembly and operation documents, industrial-grade PC boards, and necessary components for assembly; builders must furnish power supplies, enclosures, tools and consumables. The new kits are available for under $35 each.

To learn more, contact Decade Engineering at 2302 5th St. NE, Salem, OR 97303, (503) 363-5143, FAX (503) 399-9747.

Reader Service #54

AUDIO-VIDEO TECHNOLOGIES provides a possible subwoofer solution for weak bass installations. The model CPB6 is a 1 ft.^{2} woofer retailing for $60, while the DCPB66, a 2 ft.^{2} subwoofer capable of producing 460% more bass than the CPB6, costs $100.

To learn more, contact Audio-Video Technologies, 60 East Ida St., Antioch, IL 60002, (708) 395-6321.

Reader Service #65

MOREL UK LTD. has launched a new range of compact hi-fi tweeters based on their 28mm dome models MDT 29, 30 and 33. Each of the tweeters incorporates a compact, lightweight Neodymium magnet (or dual magnets) coupled to a large rear air chamber for a resonance frequency of 750Hz. Face plates on panel-mounting models measure 54mm square for mounting domes closer to woofers. Also available is a cabinet-top-mounting version. Dome diameter is larger than the more common 1″ (25cm or smaller) size, providing improved power handling and an extended low-frequency response.

The new line's MDT 39, which is 54mm long with a 3mm-thick flange, has a copper voice coil and a sensitivity of 88dB. The MDT 38 features identical characteristics, but is a top-mount version.

To learn more about the MDT 38 and 39 and other new products from Morel, contact Morel Acoustics USA, 414 Harvard St., Brookline, MA 02146, (617) 277-6663, FAX (617) 277-2415.

Reader Service #52

Now available from **SITTING DUCK SOFTWARE** is *The Sitting Duck Software Sketch Book of 70 Unique DIY Loudspeaker Enclosure Ideas*. The book contains ideas only for built-in systems, globes, unusual shapes and solutions to common problems encountered by speaker builders.

Volume 1 is available as item BKSD1 for $16.95 plus $3 S/H from Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458; (603) 924-6371, FAX (603) 924-9467.

NORTH CREEK MUSIC SYSTEMS has released the Thendara, a monitor loudspeaker kit featuring the Vifa P17WJ woofer and Scan-Speak D2905 tweeter in an acoustic suspension enclosure. The crossover is a symmetric second-order network constructed of 100% Sprague metallized polypropylene capacitors, Ohmite wirewound resistors, and 12-gauge oxygen-free Music Coil inductors. Tef-Flex AG Silver/Teflon™ cable and multicore silver solder are used throughout.

More information and the North Creek Loudspeaker Catalog may be obtained by contacting North Creek Music Systems, Route 8, PO Box 500, Speculator, NY 12164, (518) 548-3623.

Reader Service #55

SANUS SYSTEMS has released the latest in its series of loudspeaker supports, the Reference Foundation. The foundations' triangular bases are constructed of an acoustically inert material called Fountainhead that resembles solid marble, and are available in four colors: gray, emerald, sand and rose. Pillars and top plates are made of heavy-gauge steel. Other new features include top plates damped with Aquaplas Isolation strips and stronger four-point welds.

All models may be filled with sand or shot and incorporate a nonconductive speaker wire path. Adjustable downward- or upward-facing steel spikes are provided, along with Neoprene feet and speaker pads as an alternative. Reference Foundations are available in 12, 16, 20, 24 and 28" models, ranging in price from $169.99-179.99.

Sanus Systems may be reached at 2885 Country Dr., Little Canada, MN 55117, (800) 359-5520.

Reader Service #56

MTX's newly released ThunderBox software provides the tools for designing a variety of mobile audio enclosures, including sealed, vented, bandpass and isobarik push/pull dual woofer configurations. Also offered are quad plotting options for easy comparisons.

The IBM-compatible program requires a hard drive, at least 640K RAM, and VGA/EGA capabilities; it is available on 5¼" and 3½" high- and low-density disks. MTX may be reached at 555 W. Lamm Rd., Freeport, IL 61032, (800) 225-5689, FAX (815) 233-2124.

Reader Service #53

POLYDAX SPEAKER CORP. has introduced a new line consisting of nearly 100 drivers which utilize technologies such as the newly patented High Definition Aerogel (HD-A), TPX and Woven Composite woofers. The line also includes two metal dome tweeters.

To learn more, contact Polydax, a subsidiary of Audax Industries of France, at 10 Upton Dr., Wilmington, MA 01887, (508) 658-0700, FAX (508) 658-0703.

Reader Service #51

Now available is **JOSEPH AUDIO**'s RM-20 loudspeaker, which utilizes an Infinite Slope crossover to provide a steep cutoff between the drivers of >100dB/octave. Due to the cutoff, the wave interference between the speakers is nearly eliminated, increasing the system's power handling. The frequency response of the floor-standing system is 39Hz-20kHz, ±2dB.

The RM-20 is housed in a cabinet (36" × 11" × 11") made from laminated wood fiber that is 40% denser than MDF. The cabinet is formed into its shape, resulting in an enclosure offering reduced vibration. The unit retails for $1,699 in gloss black finish, $1,799 in natural oak.

For more information, contact Joseph Audio, 2 Pineridge Rd., White Plains, NY 10603, (212) 724-2509.

Reader Service #57

THE AUDIOPHILE NETWORK (TAN) is a national multiple-caller system accessed by computer and modem by dialing (818) 988-0452. The on-line system's main features include databases, forums, national classified ads, E-mail, *Orion Audio Bluebook* quotes, an ElectroStore, and a newsroom. TAN offers forums on stereo components, music, tweaks and mods, tubes, and video. The system operates 24 hours a day, seven days a week.

For the annual $24 membership fee, TAN members may access member files with no additional connect charges except for telephone usage. Many TAN system areas are available free of charge, including databases, national classified ads, the newsroom and library, and ElectroStore for on-line shopping.

To learn more, contact The Audiophile Network, 14155 Kittridge St., Van Nuys, CA 91405-4706, (818) 782-1676, FAX (818) 780-6260.

Reader Service #58

PSB SPEAKERS has introduced four midrange designs, including the PSB 500, which employs a ¾-inch cloth-dome/Ferrofluid tweeter and anti-resonance cabinet bracing. Its woofer is an 8-inch carbon-filled polypropylene cone suspended by a singular "downroll" rubber-PVC surround. This element's profile is inverted compared with conventional surrounds, so contact areas are reduced where the surround joins the cone and basket. Diaphragm decoupling is significantly improved, yielding a smooth acoustical rolloff as the woofer approaches its high-frequency operating limit.

The PSB 500 retails for $499/pair; optional SP-5 stands are $79/pair. More information may be obtained from PSB International, Inc., 633 Granite Court, Pickering, Ontario, Canada L1W 3K1.

Reader Service #60

SOUNDTECH has introduced the BT12C speaker system as an extension of its new Bantam Series Trapezoid speaker systems. The BT12C, constructed of marine-grade plywood, can be operated with optional flying hardware, and is suitable for fixed installation or portable use.

The system's design enclosure is loaded with an STS cast frame speaker with a cloth surround and polyvinyl acetate coated cone, and is coupled to a constant directivity horn tweeter. Its usable frequency response is 48Hz-21kHz, with power capability of 210W.

Further information may be obtained from SoundTech, 255 Corporate Woods Parkway, Vernon Hills, IL 60061, (708) 913-5511 or (800) 877-6863, FAX (708) 913-7772.

Reader Service #66

Reader Service #21 →

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The peculiar evil of silencing the expression of an opinion is, that it is robbing the human race; posterity as well as the exisiting generation; those who dissent from the opinion, still more than those who hold it."
—JOHN STUART MILL

Speaker Builder is published bi-monthly in the interest of the art and craft of speaker building.

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About This Issue

If you have been eager to know the whole truth about what your speakers are doing in your listening space, help for the ordinary speaker builder is at hand. **Bill Waslo** begins a three-part series on "The IMP." The acronym stands for "Impulse response Measurement and Processing." The computer aided device allows you to measure speaker performance without room effects. And that's only the beginning of what the device can do. The excitement begins on page 10.

Ralph Gonzalez brings help for you, beginning on page 24, if the box you happen to have for your woofer driver is just too small. Ralph has worked out the alignment charts as well as an explanation of what "Quasi-Monotonic" is all about.

If, after you warm up your IMP and discover your room is definitely unfriendly to the nice system you just built, **Joe Saluzzi** has more experience to offer, along with data and diagrams, about what makes a room more sound-friendly in the second installment of "What Makes Your Room Hi-Fi?" beginning on page 32.

If you are a transmission line enthusiast, **Bob Spear** and **Alex Thornhill**, reveal their final assembly methods as well as the all important design particulars of their crossover in the third installment of "A Prize-Winning Three-way TL" (p. 44). Their finishing techniques, both in tools, materials and techniques, are also helpful for any speaker project you may be contemplating.

New to these pages this time is **Bob Wayland**'s "Wayland's Woodworking World" (p. 55). Bob is that rare combination of professional cabinet maker and speaker enthusiast. You'll be delighted with his review of the hand tools you need for speaker construction as well as with the excellent list of suppliers.

Dick Pierce returns to our pages this time with some needed insight on amplifier power ratings (p. 58). If you have missed Richard's wit (sic), the reason is the absence of really difficult, basic questions about loudspeaker theory. The silence will probably continue unless you send us more thorny mysteries tough enough to intrigue the master.

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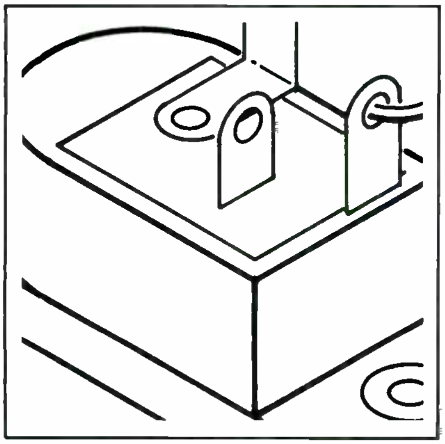
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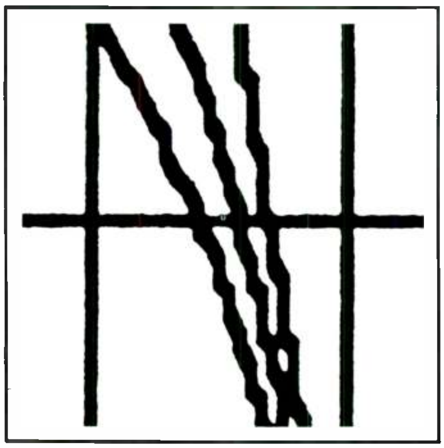
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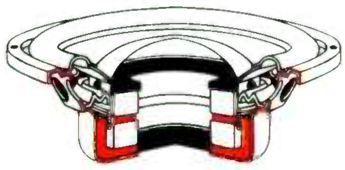
FEATURES

DEPARTMENTS

MW 142

DPC Cone Double Magnet 5″ Woofer



A 5″ unit with a unique design, incorporating an extremely large diameter aluminium voice coil for such a small unit.

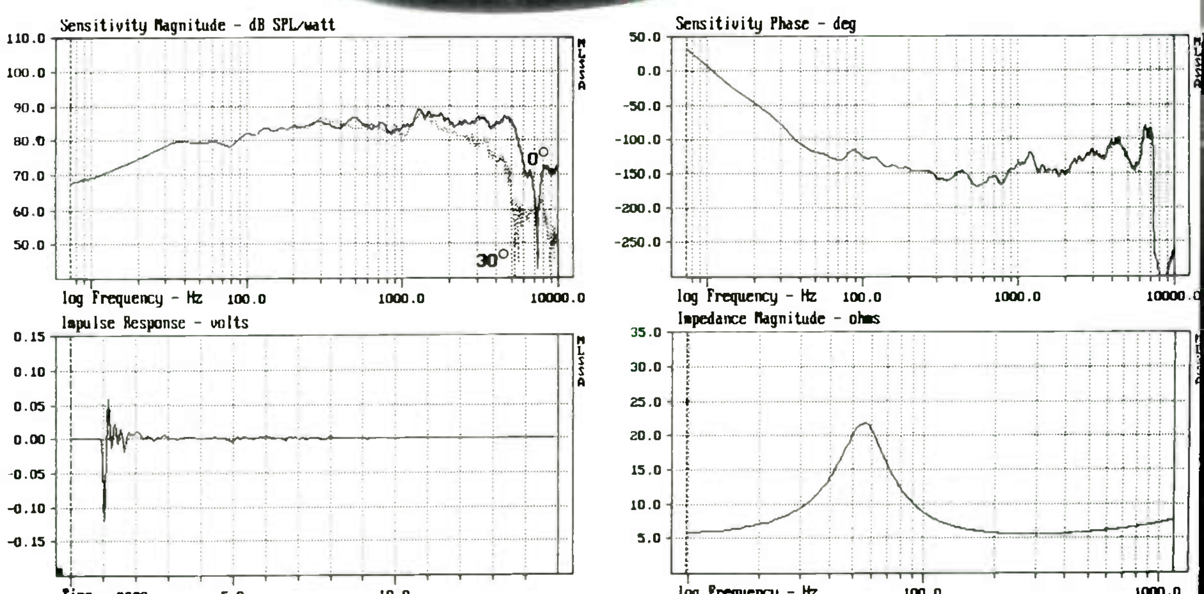
Vented double magnet system with steel chassis — damped polymer composite cone — rubber surround — smooth response to upper limit of 5 Khz with excellent on and off axis response and good roll off.

High power handling emanates from this unique design, resulting in a very impressive small bass/mid or mid range unit.

Specification

Overall Dimensions	Ø-142mm(5.5″) x 52mm(2″)
Nominal Power Handling (Din)	150 W
Transient Power — 10ms	1000 W
Voice Coil Diameter	75mm(3″)
Voice Coil Type / Former	Hexatech Aluminium
Frequency Response	48-5000 Hz
FS — Resonant Frequency	52 Hz
Sensitivity 1W/1M	86 dB
Z — Nominal Impedance	8 ohms
RE — DC Resistance	5.2 ohms
LBM — Voice Coil Inductance @ 1 Khz	0.5 mh
Magnetic Gap Width	1.35mm(0.053″)
HE — Magnetic Gap Height	5mm(0.196″)
Voice Coil Height	12mm(0.47″)
X – Max. Linear Excursion	3.5mm(0.137″)
B — Flux Density / BL Product (BXL)	0.6 T / 5.0 NA
Qms — Mechanical Q Factor	2.14
Qes — Electrical Q Factor	0.62
Q/T — Total Q Factor	0.45
Vas — Equivalent Cas Air Load	7 litres (0.25 ft³)
MMS — Moving Mass / Rmec	13gm / 2.06ns/m
SD — Effective Cone/Dome Area	90 cm²
Cone/Dome Material	DPC (Damped Polymer Composite)
Nett Weight	0.97 kg

Specifications given are as after 24 hours of running.



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Editorial

EVISCERATING IS A VISCERAL TRIP

The author of *Genius*, James Gleick's biography of Richard Feynman (Pantheon, $27.50, hardbound) begins with what is, I believe, a primary insight about the changing nature of U.S. technological life. He observes that the youthful Feynman had the advantage of all other electronics tinkerers in those early days because tube-based electronic equipment could be taken apart, unsoldered, eviscerated.

The wires, resistors, capacitors and tubes (this was in the twenties) could be pulled to pieces—or unsoldered—and put back together again. Such an exercise teaches you a good bit about the internal arrangements of electronics, and if you happen to have a schematic, it isn't difficult to figure out what is attached to what, and if you are fortunate, a primitive understanding begins to form in your mind.

That was certainly the case when I ordered my first Heathkit in the early fifties. The kit was one of the early control amps, producing all of eight watts, with volume, tone controls plus power switch and pilot light strewn across the front skirt of the chassis. The components and wiring ran naked through the chassis attaching to either a tube socket lug or a tie strip. The visibility of how the entrails were arranged gave you some idea about what the interrelationships between input and output were, and what modified what.

To a much more limited extent, that is still possible with today's microelectronics, but it is not nearly as much fun, as biographer Gleick observes. Perhaps this is the whole secret behind the decline of creative electronics, and the declining numbers choosing electronics engineering as a profession in the USA.

Fortunately for speaker builders, however, our avocation is allied to the respectable, validated craft of woodworking. (Nobody refers to anything electronic as a craft. Only those handiwork interests originating before 1900 earn that designation.) Woodcrafting is the first plus that gives it accessibility in the minds of many—even those unsure they can cope with the intricacies of watts, wires and wool.

But most of what happens in speaker building, including the passive crossover, is all dissectable. The connection and mounting techniques are more primitively satisfying with their gobs of wet silicone gel for attaching the capacitive cylinders to some rough perforated board and large, smooth power resistors whose size invites embedding in more silicone. The wires are big and colorful. The circuitry is visibly interconnective.

Although the drivers we arrange within boxes are now far more sophisticated, and made of materials more exotic than during the fifties and sixties, they are still less mysterious, accessible and far more visually appealing than most of today's tiny, enclosed, multi-legged electronics components. The tactile relationship to the speaker builder's hands is still there, as it has been all along. We know more about mounting, it is true, as in the need to sink the rim of the driver flush with its mounting surface, but routers for this requirement are cheaper and more accurate, as well as better equipped with exotic bits, than ever before.

The loudspeaker's accessibility invites upgrading as eloquently as almost any electronic device. It is becoming possible, thanks to the ingenuity of some vendors, to equip crippled drivers with new cones, or new surrounds, or both. The old models take on new life with more creative and accurately designed passive crossovers for them. Sensually shaped tweeters from today's factories replace the older, gawkier devices to excellent effect.

Old cabinetry can be modified to reduce diffraction by raw, square corners and internal stuffing replenished with newer, more measurable materials. Fiberglass and other stuffing material is now available with known densities, making their use far less a matter of guesswork than in the old days when bats of the stuff available from the corner lumberyard were undifferentiated generic, pink, itchy rolls.

The life of any speaker system can almost always be an evolutionary one, albeit limited by some first design choices. The ease of the development is certainly one of the appeals of this avocation. We live in a time when technical development is fueled by cross-discipline interaction and new composite materials enable advances almost monthly. The speaker is a retrofittable gadget.

If anyone had predicted, even a decade ago, what sort of measurement and design tools we would possess today, and at what prices, we would have at the least been highly sceptical. This issue's lead article "The IMP" is an outstanding example of such, as is Joe D'Appolito's "Mitey Mike" (*SB*, 6/90), now approved for use with the MLSSA measuring system.

The creative pleasures of the loudspeaker and its attraction as a patient worth putting under the knife for restoration to useful life is only part of the satisfaction, however. The sound from this device which transports us to the hall, the salle, or wherever music is made, is the final fulfillment. However much the cynics may smile at it, the connection between having made a device which reproduces music and the pleasure of accessing the music through it, is still a satisfaction which none other replaces.—E.T.D.

Part I

THE IMP

BY BILL WASLO

Many years ago, I constructed a set of Klipschorn copies from mail-order plans. The literature stated that these would be the epitome of high fidelity with smooth, flat response throughout the range of human hearing.

The plans covered only the cabinet; no crossover details were given. My copy of the *Radiotron Designer's Handbook* had formulas for Butterworth crossovers. I thought I could just plug in the crossover frequencies and speaker impedances, and out would come the proper component values. For level matching between the drivers, I figured I would use L-pads on all three.

As you can imagine, those L-pad knobs got a workout over the next few years. The proper tuned-by-ear setting, if there was one, seemed to change with every record. For some inexplicable reason, that

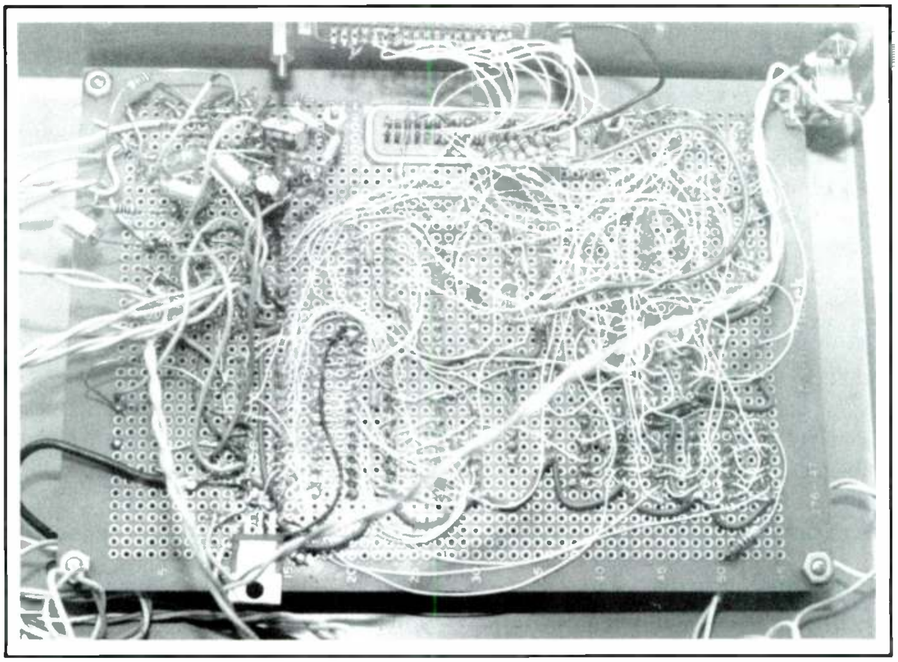

PHOTO 1: Prototype soldered together with wire-wrap wire.

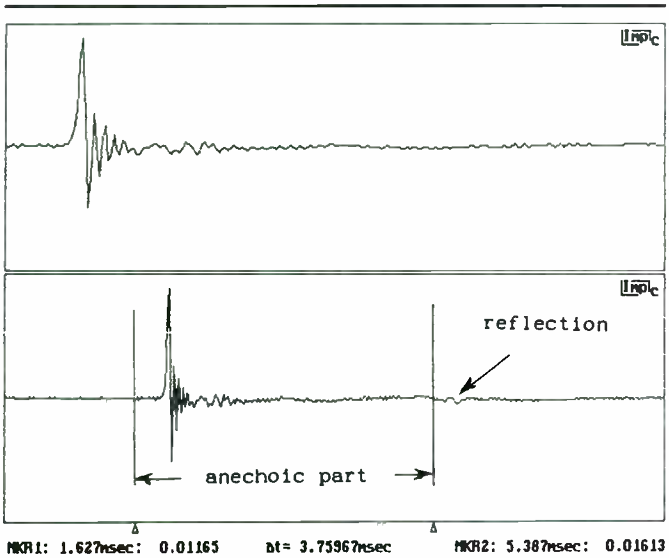

FIGURE 1: Lower plot: impulse response of loudspeaker with anechoic portion marked. Upper plot: anechoic portion expanded.

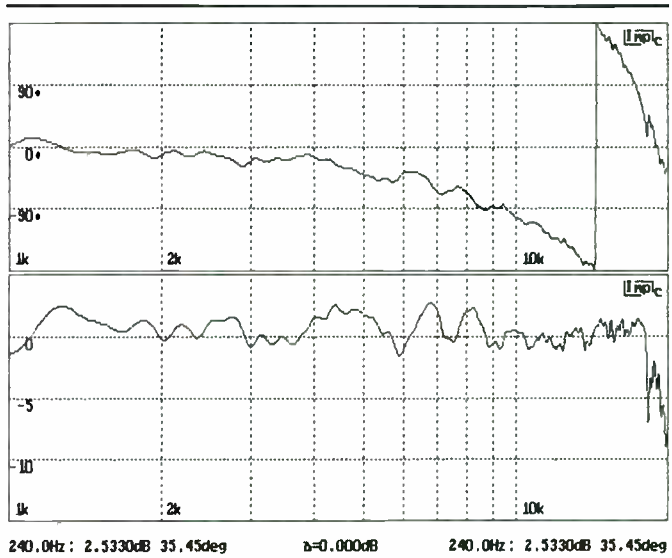

FIGURE 2: Frequency response curves corresponding to impulse response of *Fig. 1*. Lower plot: amplitude information. Upper plot: phase information.

one out of an infinite number of possible combinations continued to elude me.

Then I got smart. I borrowed a sound-level meter and an audio sine-wave generator and proceeded with the scientific approach to crossover tweaking. I placed the meter at the normal listening position and connected the generator to my amp. I thought it would be a simple matter of sweeping the audio frequency range through each channel and adjusting some knobs or components until the needle of the sound-level meter stayed steady as I went from 30Hz to 15kHz.

The needle bounced all over the place. The range knob on the meter had to be switched over 30dB just to cover the variations in a single driver's range. The needle would jump across the meter scale with the slightest nudge of the generator's frequency knob. And moving anything, particularly myself, around the room would generate wild fluctuations at a single fixed frequency.

INTERFERENCE. More research revealed the problem: interference effects. Sound waves emanating from my speakers went not only to the sound-level meter but also to walls, floors, ceilings, furniture, people, and anything else. The waves were then reflected off these items. At the instant a direct wave from the speaker was pushing on the meter's microphone, the reflected waves might be either pushing the same way or pulling the opposite way, depending on the distances and the test frequency. The resulting measured frequency response was ghastly.

To get around this measurement difficulty, a few speaker companies have special rooms called anechoic chambers, with walls off of which sound cannot coherently reflect. These companies measure their speakers' performance, and the consumer must take their word for it. I never did learn the true response of my Klipschorn copies, since I sold them before I could do so.

As I thought about this issue, I considered the need for anechoic chambers. Isn't most real-world listening done in a reflective room? If the actual response is

Continued on page 13

ABOUT THE AUTHOR

Bill Waslo is an electrical engineer for a midwestern electronics firm and is involved with the design of RF filters and analog signal processing. He is a graduate of the University of Cincinnati, and has been involved with electronics since he was allowed to hold a soldering iron. Besides music and audio, his interests are his family, organic gardening, and mystery novels.

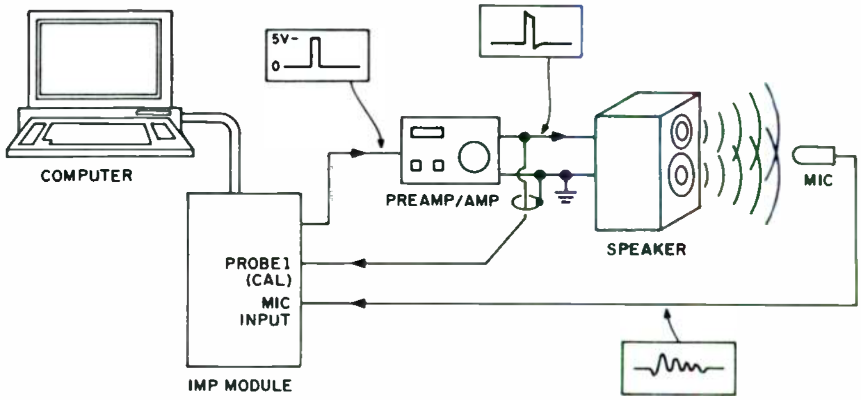

FIGURE 3: IMP configuration for recording acoustic impulse response.

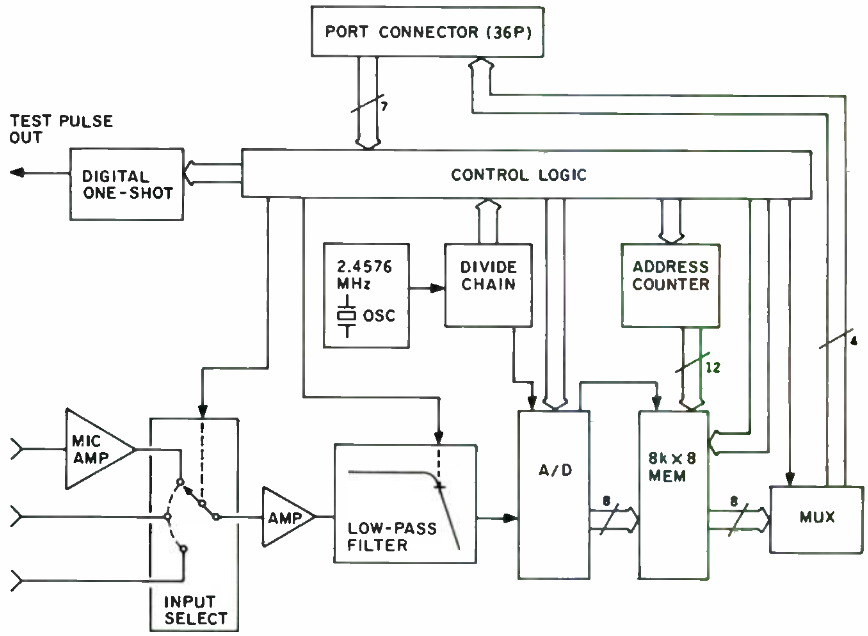

FIGURE 4: Functional block diagram of IMP module.

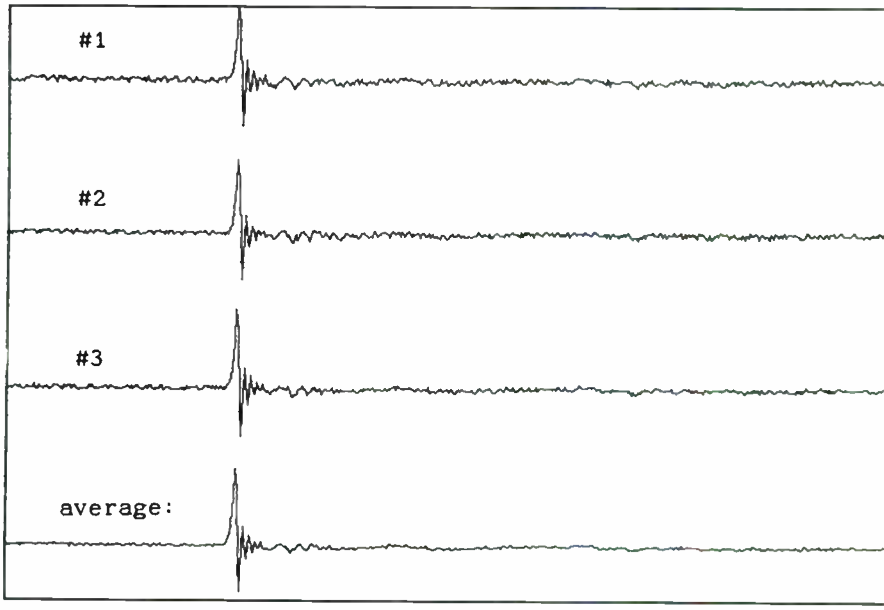

FIGURE 5: Three noisy impulse response plots and a quieter plot obtained by averaging them.

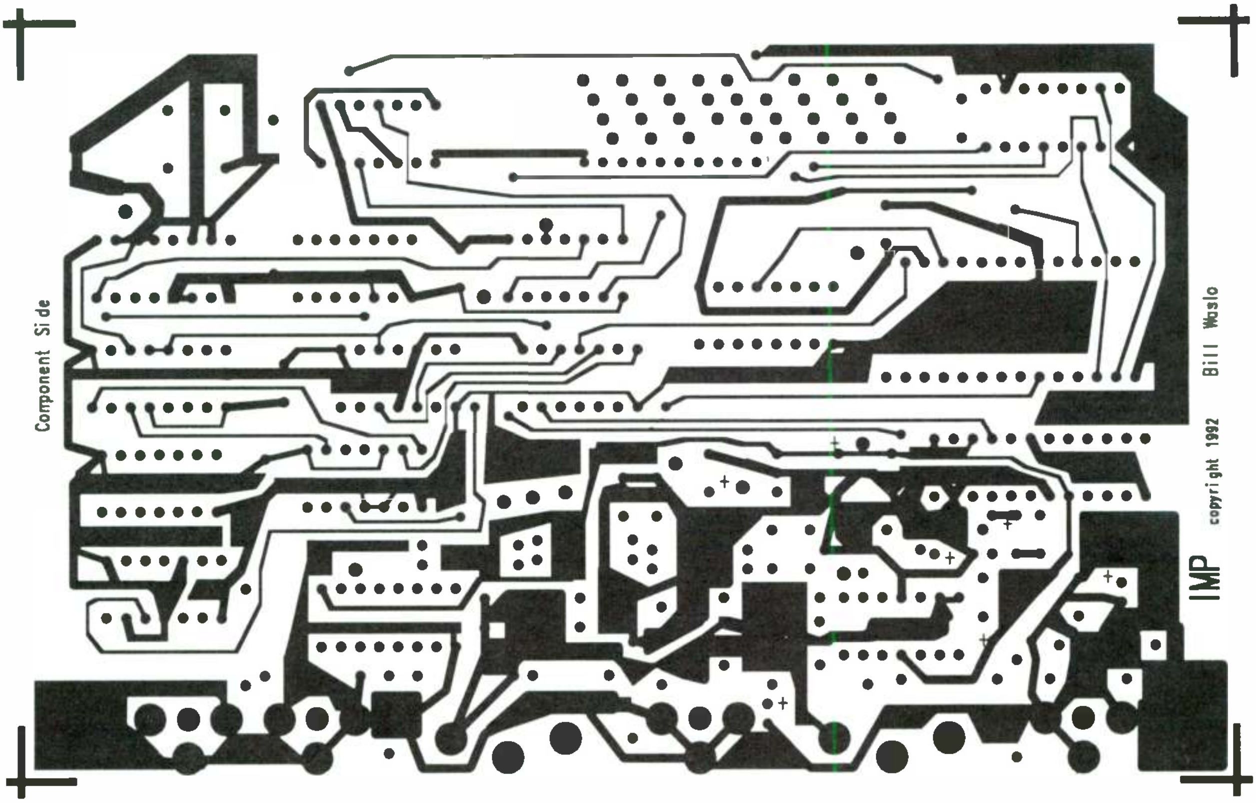

FIGURE 6: Circuit board pattern, component side foil view.

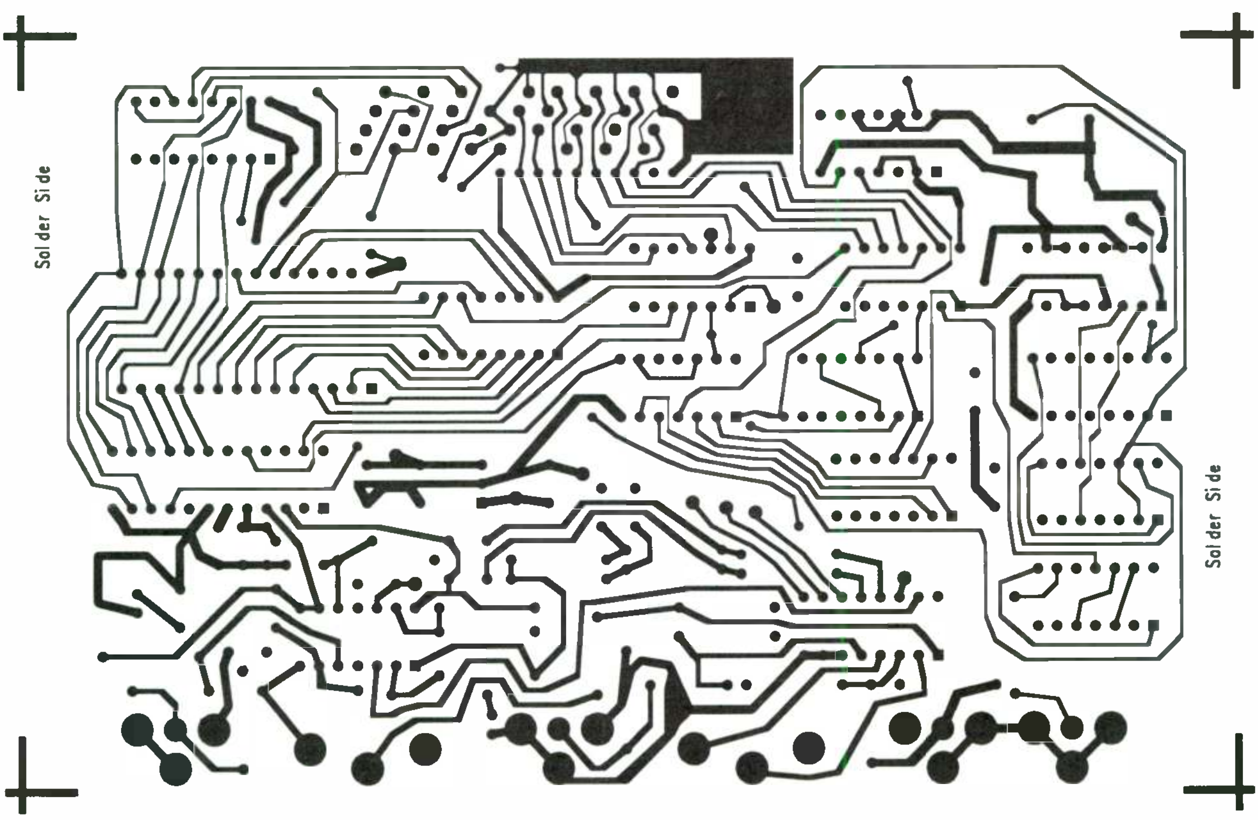

FIGURE 7: Circuit board pattern, bottom side foil view.

Continued from page 11

a 30dB roller-coaster ride that varies with just about anything in the room, how is the music recognizable, much less high fidelity? Why should it matter how flat the speaker response is with such effects wreaking havoc?

People don't get that much musical information from pure, steady tones. Monotones are boring, if not annoying. Much of the musical effect comes from transient information (attacks and decays), which consists of a continuum of frequencies rather than distinct tones. These transients also reflect around the room, but cannot be totally notched out as can a single frequency.

While the room's effects can't be ignored, the brain focuses to some extent on the first arrivals of the transients, and this is the performance area for which the speaker can be held responsible. A worthwhile goal is to ensure that the first arrivals match the original recorded sounds. The frequency response, before echoes, should be flat.

Nature has provided us with a free anechoic chamber: the outdoors. You can move your equipment into the back yard, aim your speaker at the sky, hang a microphone over it, and start measuring. When I tried this on a two-way system, it worked—sort of. I had to wait for a calm day, or the microphone would convert every little breeze into violent pounding of the meter movement. And I had to work around noise from lawn mowers, children, aircraft, dogs, and other sources. I had one messy response curve to show for about three hours of effort: magnitude only, no phase data. I haven't tried it since.

RAPID TRANSIENT. Do you have to build an anechoic chamber to design and adjust your speakers? Not necessarily. A theorem derived by the mathematician Joseph Fourier points to an alternative.

To duplicate a rapid transient, a reproducer must exhibit a perfect anechoic frequency response. Conversely, the way a speaker reproduces a known transient can reveal its frequency response. A plot of a transient impulse response looks like a frozen oscilloscope plot (*Fig. 1*). The lower plot shows about 8ms of the impulse response of a home-brewed three-way speaker, with the anechoic portion marked off and then expanded in the upper plot. Notice the wiggle due to the first reflection to the right of the marked-off region of the lower plot.

If you can record this transient response and find a way to get it into your computer's memory, you can transform it into a frequency response curve (*Fig. 2*). You can get both amplitude (lower plot) and phase information (upper plot). If you don't include the echoes in the transient data, you can get the anechoic frequency response—no chamber required.

If you build the impulse response measurement and processing (IMP) board described here, you'll be able to do just that, as well as perform quite a few other useful operations. If you have a stereo system and an IBM-compatible PC with a high-resolution monitor, you are well on your way to owning a sophisticated measurement system.

DIGITAL WIZARD. With analog and digital support circuitry, software, microphone capsule, power supply, controls, circuit board, and memory, you can build the IMP from a kit for about $250 (knobs, cables, probe clips, mounting hardware, and case are not included). If you are particularly resourceful and want to rough it, you may be able to cut

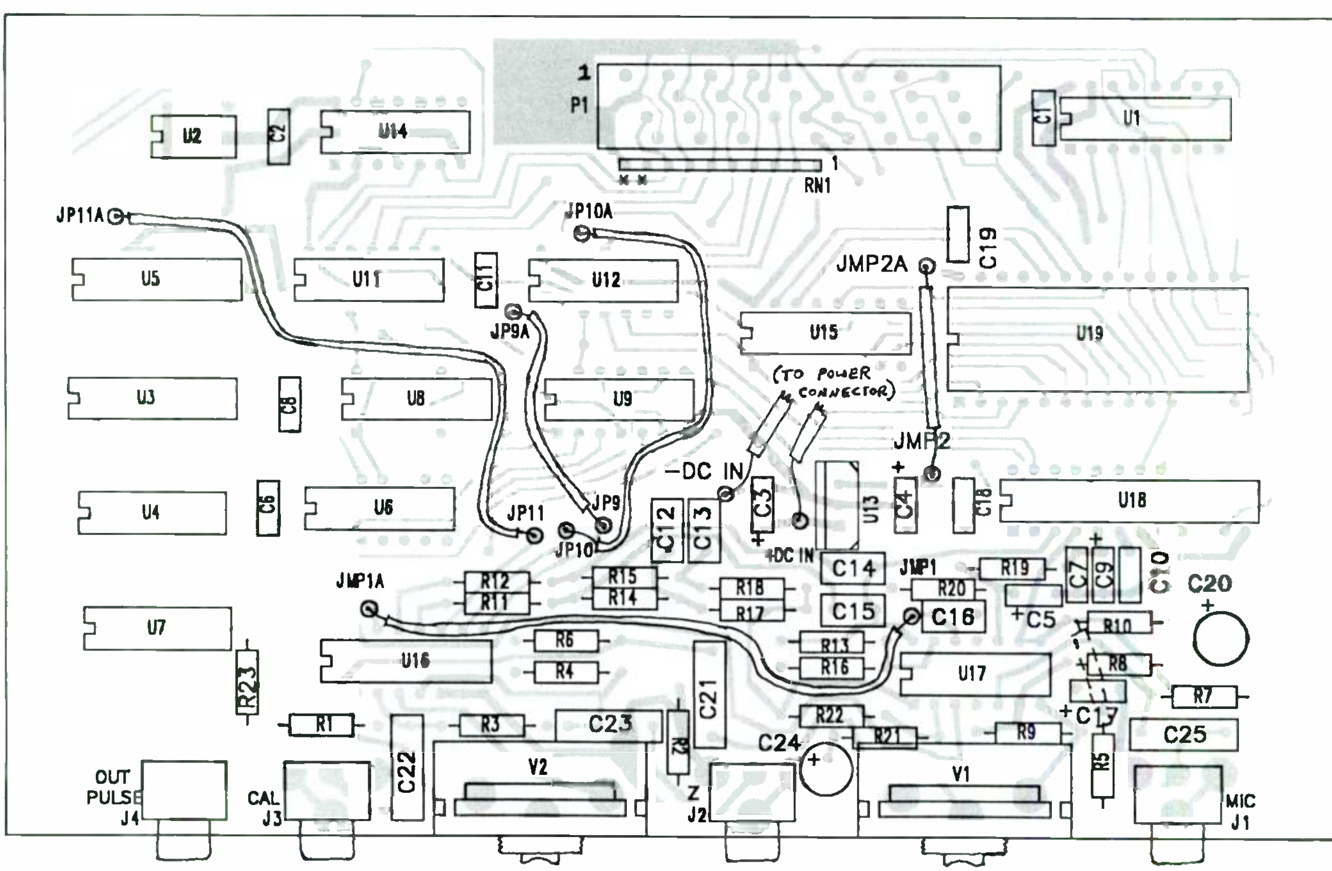

FIGURE 8: Parts placement for circuit board. Note the placement of jumpers.

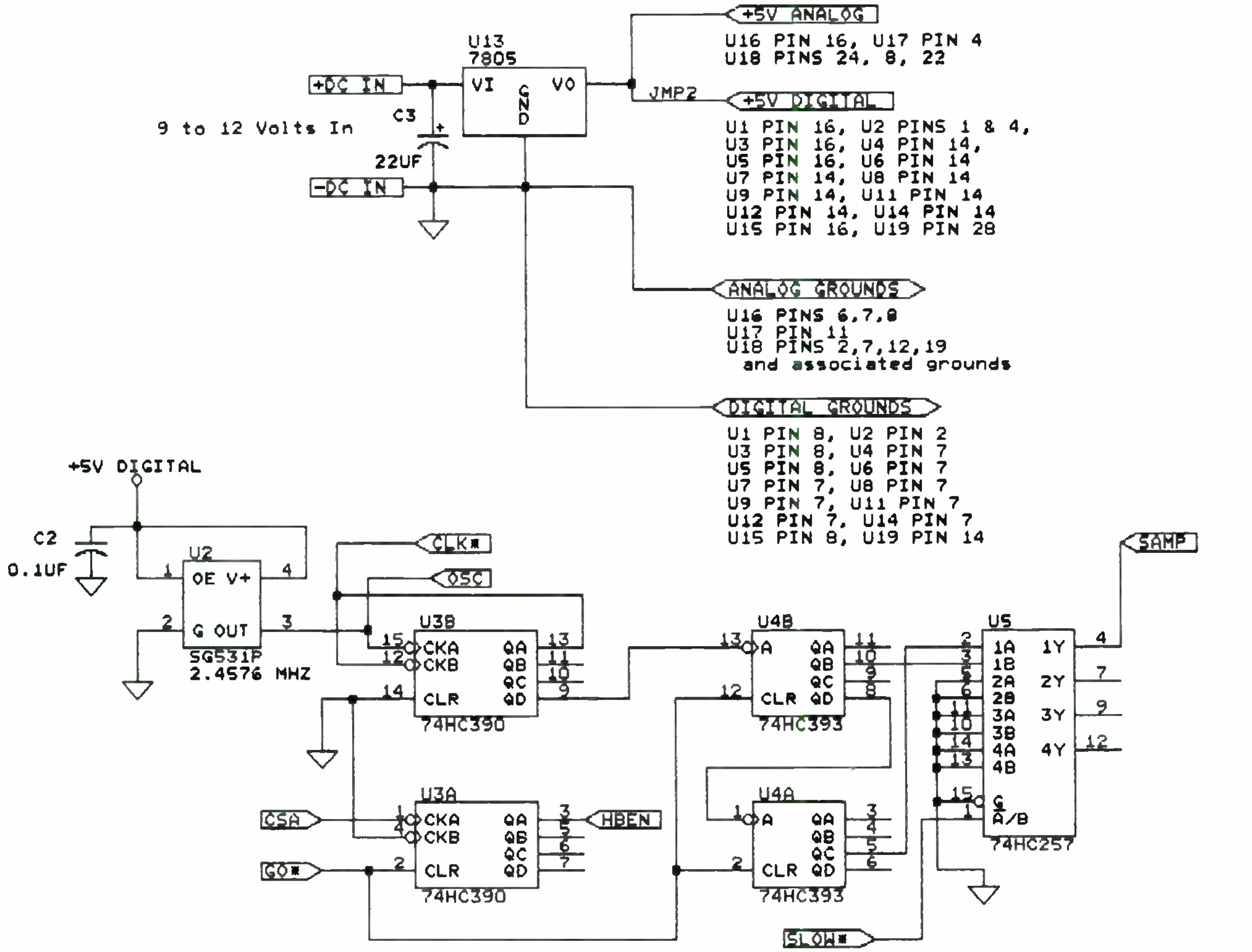

FIGURE 9: Schematic drawing of power wiring and timing circuitry.

costs further by scrounging some of your parts from surplus suppliers or your junk box. With this system, you will have capabilities which were once beyond those of many speaker manufacturers.

The IMP is a transient capture system and software package which allows collection and analysis of 12-bit analog data up to 4,095 samples in length. Sample rates are selectable at either 61.441kHz or 1.92kHz which, along with the internal filtering, allows measurements from several hertz to 20kHz.

The test signal appears in the form of a single rectangular pulse, which is fed through the amplifier to the speaker or driver under test (*Fig. 3*). The pulse width depends on the sample rate. The microphone cartridge picks up the acoustic response and delivers it to the IMP module which digitizes it. The amplifier output also can be sampled by means of a probe to correct for errors in the pulse spectrum and amplifier response. Also, you can measure an electrical response with another probe input to determine complex impedance curves or crossover responses. The data is fed to an IBM-compatible PC through its parallel printer port, which also controls the IMP.

In addition to rapid anechoic response (magnitude and phase) measurements, you can determine impedance curves and filter rolloffs for crossover design or ported box alignment, look at the frequency content of individual echoes, check the effectiveness of acoustic absorbers, measure room responses, investigate resonances with spectral decay ("waterfall") plots, measure crossover inductor and capacitor values, and determine radiation characteristics. The IMP can also be used in a manufacturing environment for design, alignment, or quality control.

The IMP, along with an integrated amplifier and a computer, can serve as a network, spectrum, or impedance analyzer without requiring a sine-wave generator, level meter, oscilloscope, frequency counter, or any other expensive equipment normally associated with loudspeaker measurements. Best of all, you need not merely theorize about whether your octahedral box reduces standing waves or whether an exotic treatment alleviates the directivity problems of your dipole panels.

The IMP is not the first system to provide this capability, nor is it the most sophisticated. The MLSSA system, for instance, goes one step further and uses a pseudorandom sequence as the test signal, and a thorough analysis software package for professional applications. I've also seen ads for the LMS system, which includes gated sine-wave generation and network simulation capabilities.

I can't afford the MLSSA or LMS, and neither can many other amateur or small-scale commercial speaker builders. The IMP provides answers and is affordable for builders with more modest budgets. As an added benefit, the IMP's use of the printer interface for connection makes the system portable. You can use it to analyze speaker systems anywhere there's a PC.

As with the MLSSA, some smarts are required to use the system fully. The best way to learn is through hands-on experience. I've tried to make the hardware and software as easy to use as

Continued on page 16

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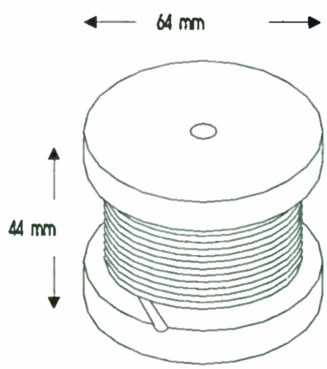

mH	DCR Ω	Price	mH	DCR Ω	Price
1.0	.092	$11.25	3.0	.179	$13.50
1.25	.105	11.75	3.3	.189	13.60
1.5	.114	12.00	3.7	.204	13.75
1.7	.126	12.25	4.0	.213	14.00
2.0	.139	12.50	4.3	.226	14.75
2.25	.149	12.75	4.7	.237	15.00
2.5	.156	13.00	5.0	.248	15.25
2.7	.166	13.25	6.0	.288	16.25

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- Best for subwoofer applications
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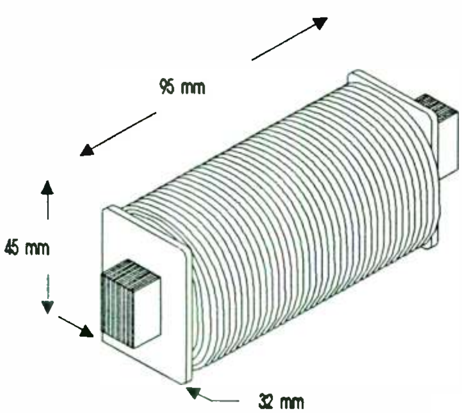
- Low DCR



mH	DCR Ω	Price	mH	DCR Ω	Price
4.0	.210	$11.25	8.0	.345	$13.50
4.5	.231	11.75	8.5	.357	13.75
5.0	.242	12.00	9.0	.364	14.50
5.5	.257	12.25	10.0	.376	14.75
6.0	.272	12.50	12.0	.426	15.50
6.5	.287	12.75	13.0	.450	16.75
7.0	.307	13.00	15.0	.505	17.50
7.5	.320	13.25			

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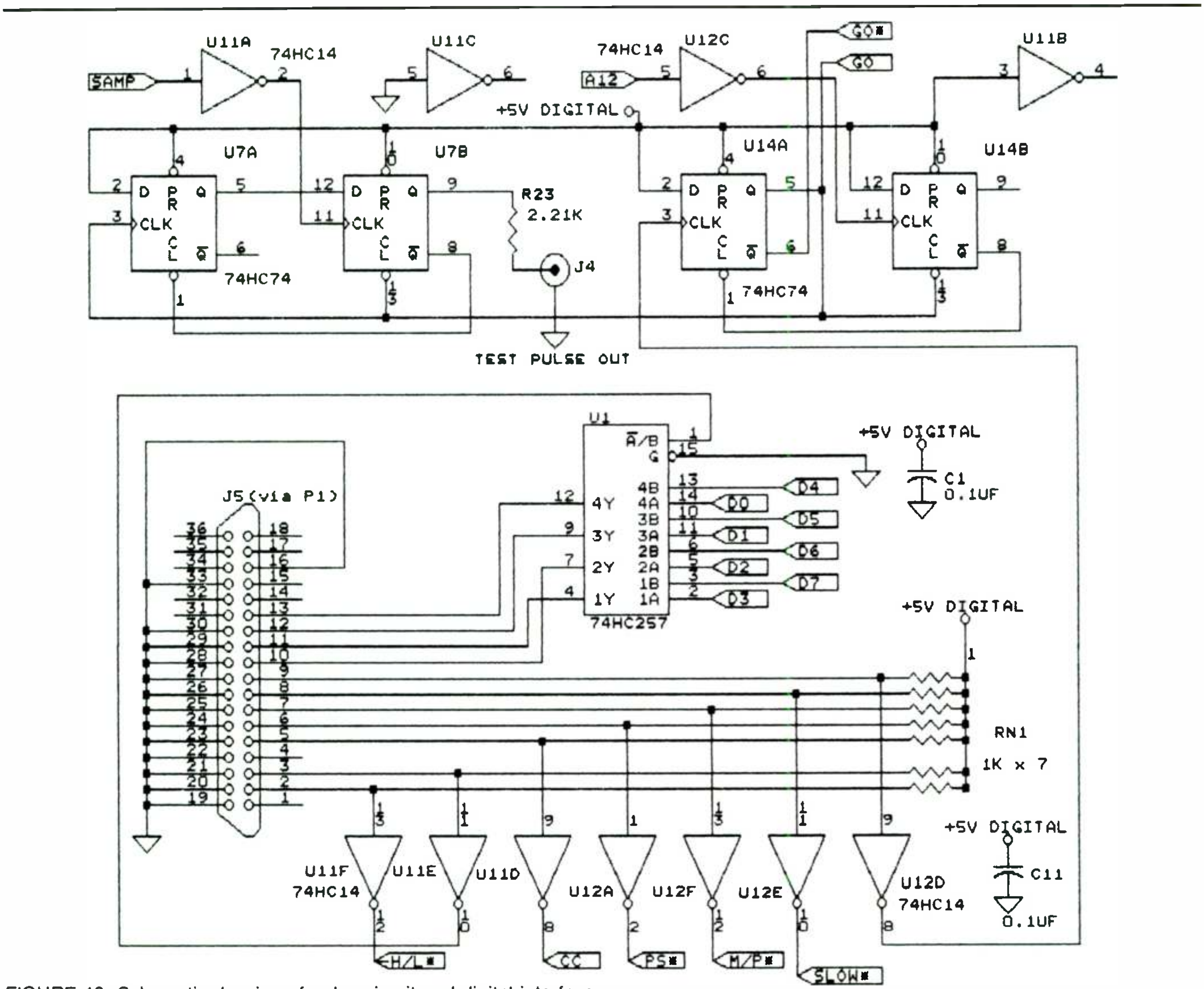

FIGURE 10: Schematic drawing of pulse circuit and digital interface.

Continued from page 14

possible, without limiting their versatility. I hope the IMP will spark a new flurry of investigations, *SB* articles, tips, and discussions.

HARDWARE. In addition to the IMP board, power supply, and software, you need the following:

- An IBM-compatible PC with 640K of memory, DOS 3.1 or higher, and a high-resolution display (Hercules, EGA, or VGA; CGA can't do it). The system must include a parallel printer port and a cable with a standard 36-pin Centronics-type plug. A math coprocessor is not required.
- A power amp with a gain (volume) control or preamp. Your existing stereo system amp/preamp should work fine. I have a small 20W "utility amplifier" that works well for dedicated measuring. Amplifier quality matters little; the "CAL" probe and software calibrate out errors.
- Cabling to run from the IMP board to the amp, and from the mike to the IMP. You also need cables to attach the probes.
- A case and mounting hardware for the IMP board, if desired.
- A microphone stand or functional equivalent. I made mine by mounting a broomstick on a 12″ × 12″ × 0.75″ piece of particleboard. A steel rod from the local hardware store serves as the boom, and a glob of modeling clay is the counterweight. Duct tape holds everything together and allows clumsy adjustment. This scheme is quick and cheap, but you can also use a camera tripod, music stand, or inverted bar stool.

IMP ANATOMY. The heart of the IMP is the MAX190 analog-to-digital (A/D) converter, which, like the rest of the IMP system, operates off a single internally regulated +5V supply. This allows it to be powered from an inexpensive, plug-in "battery eliminator"-type power supply of 9–12V DC at 100mA or more. You can obtain such a unit from Radio Shack.

For insight into the IMP's inner workings, refer to *Fig. 4*. You don't need to understand its anatomy to make measurements with it, but a cursory glance may give you some idea of what the system is capable of.

The sampler timing is derived from a crystal oscillator and divider chain, for frequency accuracy and stability. The sample clock is processed to drive a counter, which generates the addresses to the memory chip for saving the data until it is ready to be read into the computer.

Several flip-flops and some logic gates (labeled "control logic") set up synchronization, and generate the control pulses and sequences to run the A/D converter and memory operations. Another set of flip-flops configured as a digital one-shot

Continued on page 18

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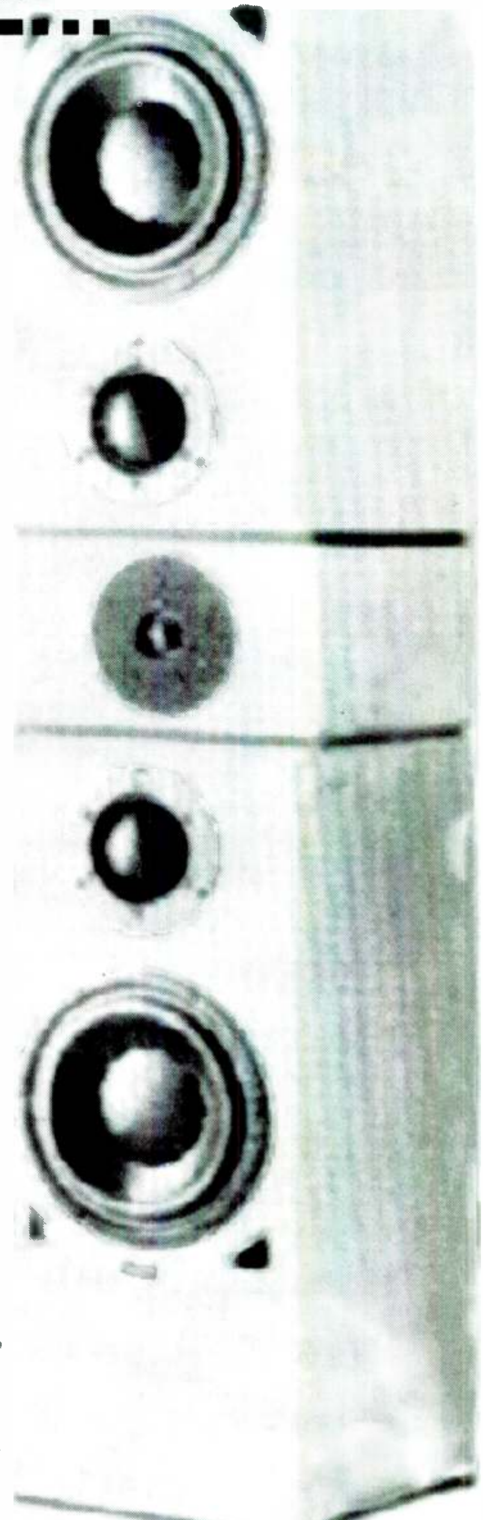

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Continued from page 16
generates the output test pulse, also to crystal accuracy.

Analog processing, such as microphone amplification and antialias filtering, is performed by a CMOS quad op amp, the TLC274, chosen to provide maximum output signal level from the +5V supply. Input selection and control of the filter cutoff frequency are accomplished with a 4053 analog switch IC.

I kept the printer port interface to the computer as simple as possible. All input lines use hysteresis to avoid noise problems, and outputs to the computer are buffered. The IMP sports a Centronics-type receptacle, which can be connected to the PC using your printer cable.

TIME AND DATA. When data is to be collected, the computer sets the IMP's sample rate and input configuration, and resets the memory address counter. It then initiates a set of conversions and sends the output test pulse to your preamp and power amplifier. Each time this happens, 4,095 sequential 12-bit digital samples of the analog response to the test signal are recorded at a crystal-controlled rate. When these have been digitized and stored, the computer resets the address counter and reads the data from memory at its own pace, 4 bits at a time. Once the data is in memory, the software takes over and analysis begins.

The conversion from transient to frequency response is based on a mathematical operation known as the Fast Fourier Transform. The IMP records a speaker's time response to an approximate impulse and the computer translates it into the frequency response. The computer corrects the response by using additional data from a CAL probe of the actual pulse waveform, also recorded by the IMP, as it is delivered from the amplifier to the speaker. This CAL data need not be collected with each acoustic impulse, since the amplifier characteristic should be constant.

If you include the echoes in the transformation (visible in *Fig. 1*), you won't get the anechoic response. With the IMP software you can edit the time waveform to just the anechoic portion. This time period restriction does limit the frequency response that can be accurately measured. If a low-frequency cycle is longer than the time period being transformed, you can't trust the results for that frequency and below. In most rooms, however, you can obtain a good curve down to less than 1kHz.

You can measure the lower frequencies by using the IMP with near-field techniques. If you place the mike close to a driver, the direct signal picked up will be much stronger than any reflected signals. If you use this technique, you should measure each driver or vent separately. The near-field time responses do not require editing and truncation, so

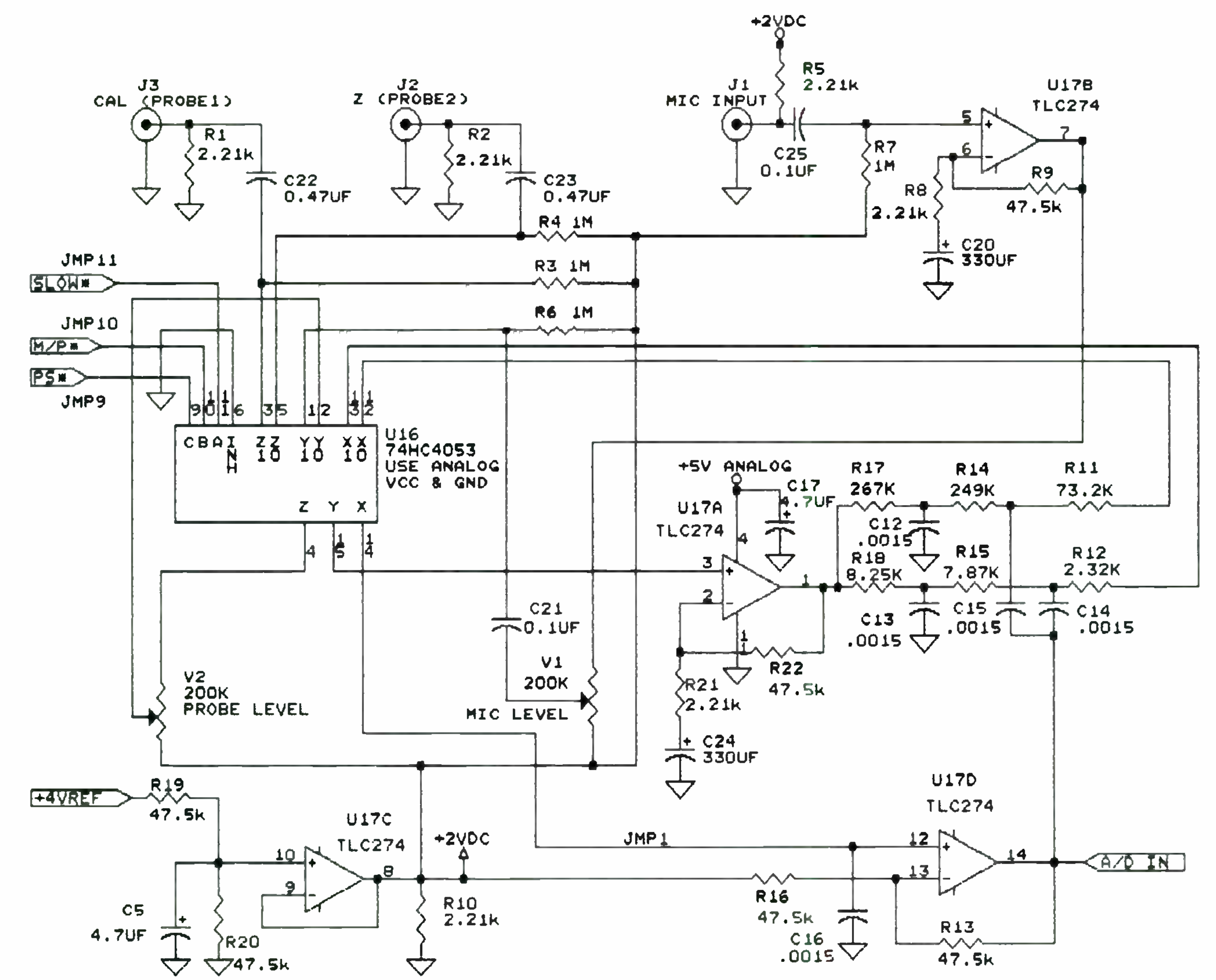

FIGURE 11: Schematic drawing of analog gain, switching, and filtering.

you can obtain low-frequency results. The IMP software even has a merge facility to allow multiple responses to be cut-and-pasted or vector-summed to get a hybrid full-band response.

You can also use this piecemeal approach at higher frequencies, but cabinet diffraction and small differences in microphone distance can dramatically affect the summed response of a high-frequency driver. At these frequencies, it's better to get actual phasing and combination rather than simulated.

When a waveform enters the computer, it usually contains a large amount of noise from a furnace, an air conditioner, plumbing, a refrigerator, or other source. Some random electrical noise is also present. You can deal with these noises by taking a number of waveform samples rather than just one, then averaging values at each time point (*Fig. 5*). With the IMP software, this requires only a little time and no extra effort.

Your speaker will produce the same waveform with each identical pulse input, but the noise will be different each time. Averaging emphasizes the repeatable response and minimizes the sporadic noise. If you want a cleaner, quieter waveform, tell the computer to average a larger number of samples (this will be described later).

Some nonrandom noises will be the same with each sample and are harder to avoid, showing up as sharp ridges on waterfall plots. Stray pickup of the clocking signals in the IMP circuitry shows up as spurious responses, with the severity depending to a large part on construction technique. Also, low-frequency plots often show irregularities at 60Hz, thanks to AC line pickup. Computer monitors can also generate interfering fields visible on response and waterfall plots.

CONSTRUCTION. You can build the IMP using point-to-point wiring. But construction and debugging time will be greatly reduced, and the device will probably be less susceptible to spurious responses, if you use a PC board (*Figs. 6, 7* and *8*).

Double-sided techniques are required, and the holes are designated as plated-through. If you make your own board, you must make solder connections on both sides or add jumper wires where needed to compensate for the lack of plated-through connections. Most of the signal connections are on the board's solder side to minimize the work involved.

The schematic drawing is in four sections (*Figs. 9, 10, 11* and *12*). If you'd like to try the direct-wiring approach, use good, heavy grounds for the analog section and connect them as shown in *Fig. 9*, joining analog and digital grounds (and analog and digital +5V supplies) only at the regulator. Avoid wire-wrap construction in or near the analog circuitry, as it tends to radiate or pick up noise.

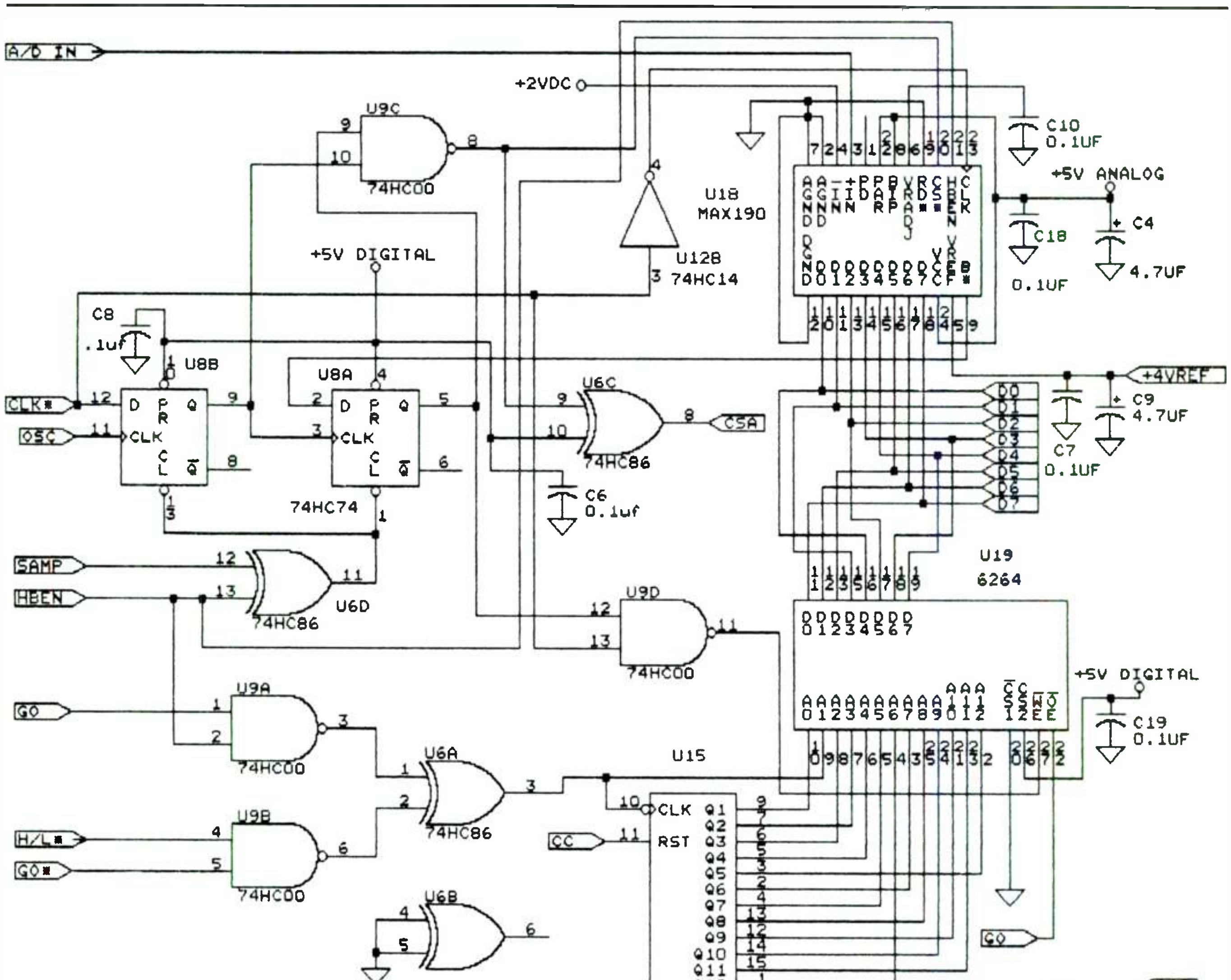

FIGURE 12: Schematic drawing of A/D, memory, and control circuitry.

The wire-wrap wire is handy for point-to-point wiring, since you can solder right through the insulation with a reasonably hot iron. That way you can avoid stripping the insulation at many connections and speed up the process considerably. The board will, however, look like a rat's nest when you are done (*Photo 1*), and trouble-shooting will be more difficult if problems arise.

Mount parallel port connector J5 on the back of the case. In the kit, it connects to the board via a short mass-termination ribbon cable and adapter P1. If you get the connector and adapter yourself, you must devise a way to press the ribbon cable into the units. (All connections are automatically made when the back of the connector pins pierce the cable wires.) I have had success using a vise to press the cable into J5 and P1; use small pieces of metal to press between the pins of P1 and avoid crushing them.

The ribbon cable will have 36 conductors at the J5 end, with the Pin 36 and Pin 18 wires cut back about an inch before reaching P1, as these pins are not needed and P1 provides for only 34 pins. Make sure the orientation is correct—Pin 1 of J5 is at the same edge of the ribbon as the designated pin of P1—and the ribbon cable is straight so that all the wires are connected.

Alternatively, you can run discrete wiring from a solder termination-type Centronics connector for J5 to the PC board holes provided in the P1 outline. The P1 hole pattern (*Fig. 13*) shows the matching pin numbers for the 36-pin parallel port connector J5. Pin 1 on the circuit board is at the end of the hole pattern, toward U14 and nearest the board's back edge. All the pins marked as common ground can be connected together at J5 and connected to the Pin 19 hole of P1 with a single line if you are using discrete wiring.

The etched board is designed for circuit board-mountable controls and analog signal connectors, which are supplied with the kit. Their use further minimizes point-to-point wiring and makes construction easier. You can use chassis-mount connectors and controls if you connect them with short lengths of wire. Use RCA phono connectors for all analog inputs and outputs.

SIMPLY SHOCKING. The power supply can be any type from 9–12V DC at 100mA or greater. It connects to the IMP board at the two pads marked "+DC IN" and "−DC IN." Make sure to get the power supply polarity correct, as CMOS circuitry is unforgiving of reversed supplies, and component death will surely result. I recommend that a 1N4001 diode be installed in the positive lead, as shown in *Fig. 14*, to avoid disaster. There appears to be no standard polarity for these power supply plugs; some have the center pin as positive (most 9V DC types), some as negative (many 12V DC types). If you are not using the kit, check the supplies with a meter *before* connecting. If you are using the kit, wire the connector as shown in *Fig. 14*, and use only the supplied power adapter.

Continued on page 22

TABLE 1

IMP PARTS LIST

QTY.	PART	DESCRIPTION
Capacitors		
9	C1, 2, 6–8, 10 11, 18, 19	0.1μF, 50V, ceramic
1	C3	22μF, 25V, aluminum radial electrolytic
4	C4, 5, 9, 17	4.7μF, 10V, tantalum electrolytic
5	C12–15, 16	0.0015μF (1,500pF), 5%, film
2	C20, 24	330μF, 6.3V, aluminum radial electrolytic (100μF; 6.3V OK, too)
2	C21, 25	0.1μF, film
2	C22, 23	0.47μF, 5%, film
Resistors		
1	RN1	1k × 7 SIP resistor network
7	R1, 2, 5, 8, 10, 21, 23	2.21k, 1%, 0.25W metal film
4	R3, 4, 6, 7	1M, 5%, 0.25W carbon film
8	R9, 13, 16, 19, 20, 22, Rp1, Rp2	47.5k, 1%, 0.25W, metal film (Rp1 and Rp2 used in series with hot leads of probes)
1	R11	73.2k, 1%, 0.25W metal film
1	R12	2.32k, 1%, 0.25W metal film
1	R14	249k, 1%, 0.25W metal film
1	R15	7.87k, 1%, 0.25W metal film
1	R17	267k, 1%, 0.25W metal film
1	R18	8.25k, 1%, 0.25W metal film
4	J1–4	PC-mount RCA phono jacks, Mouser #161-4216
1	J5	36-pin Centronics-compatible parallel interface receptacle; use IDC type if P1 and ribbon cable will be used (see text)
1	J6	DC power connector: insulated 2.1mm DC power jack
1	J7–9	mike connector: in-line shielded RCA phono jack, used for connection through a short twisted pair to the mike capsule (if not using Mitey Mike) and to connect probes
1		mike: Digi-Key #P9932 or Mitey Mike
1	P1	34-pin PC board connector, mass-termination type, if ribbon cable used with J5 (see text), Digi-Key #CPC34T or equivalent
2	U1, 5	74HC257
1	U2	Epson SG-531P 2.4576MHz CMOS crystal oscillator, Digi-Key #SE1202
1	U3	74HC390
1	U4	74HC393
1	U6	74HC86
3	U7, 8, 14	74HC74
1	U9	74HC00
1	U10	not used
2	U11, 12	74HC14
1	U13	7805 or 78M05 T0-220 positive voltage regulator
1	U15	74HC4040
1	U16	74HC4053
1	U17	TLC274CN, Texas Instruments CMOS quad op amp
1	U18	MAX190 12-bit A/D converter (MAXIM)
1	U19	6264-15, 6264-15L, or faster version, 8k × 8 static RAM chip
2	V1, 2	200k PC Mount potentiometer, Mouser #314-1410-200K
1	D1	1N4001 rectifier

Miscellaneous

Plug-in power supply, 9 or 12V DC at 100mA or more (see text about proper polarity)
IC sockets recommended for all ICs except U2 and U13
Etched PC board or perforated board and hookup wire
IMP control and process software
2 long mono patch cables for microphone extension and amplifier feed
1 long stereo patch cable for probe connection
alligator clips for probe
case and mounting hardware

Note: All 74 series ICs can be HC, HCT, or ACT type in DIP package.

Continued from page 20

An imperceptible static spark can blow these ICs before they are safely installed in the IMP. I recommend sockets for all the chips except the regulator and clock oscillator to minimize the time spent handling the devices. If you can ground yourself while installing the ICs, do it. If not, try to keep the ICs on conductive foam until you are ready to install them. Put a sheet of aluminum foil on your bench under your work, and keep a bare elbow on it. Install the ICs last, and maybe while your hair is still wet after a shower. Damage is not common, but very troublesome when it occurs.

Construction of this board is quite different from that of the typical audio project. More than 450 connections must be soldered, and the pads are rather close together. Make sure you use a small-tipped soldering iron and take your time.

Install the parts as shown in *Fig. 8*, taking great care to orient the regulator and electrolytic capacitors. Be careful to install the ICs in the correct orientation. The resistors designated "RN1" are contained in a single SIP package in the kit, and the orientation of this package also must be as shown, with the last two holes (those marked with "X" toward U14) unused. If you are building from scratch, you can substitute individual resistors. Just tie their common leads together and jumper to the common pin hole (labeled "1") in the board. Five jumper wires are required between pads on top of the board.

(1) 3 5 7 26• 12 (14) 16•
19• 21• 23• 25• 9 28• 30• (32) (34)
2 (4) 6 8 27• 11 13 (15) (17)
20• 22• 24• 10 29• (31) 33• 35

COMPONENT SIDE VIEW

FIGURE 13: P1 hole pattern marked with corresponding J5 pin numbers. Numbers in parentheses denote unused pins; asterisk denotes common ground pins (single wire will suffice for all).

An error was made in the PC board layout, connecting R5 to +5V analog instead of to the proper connection at +2V DC. (The circuit will work with connection to +5V, but the mike input will pick up excessive digital noise.) To avoid the expense and time involved in redoing the board layout and films, the inside pad of R5 (nearest to C17) on the solder side of the board was isolated.

If you will be using the Mitey Mike (*SB* 6/90, p. 10) or another self-powered microphone, connect this pad to ground. Otherwise, connect it to the inside pad of R10 (the one nearest C16) on the solder side of the board using about an inch of hookup wire, as indicated by the dotted lines in *Fig. 8*.

MIGHTY IMP. The microphone capsule is the same electret capsule as that used in the Mitey Mike, and is wired to an RCA phono jack with about 7" of twisted-pair wire. The pad that connects to the capsule case is ground. Install the mike in some kind of holder. You can emulate the Mitey Mike or use a disposable ball-point pen body for minimum cost. The capsule is powered from the IMP board through its signal cable, which can be a long (typically about 30') mono patch cord. Total capacitance should be kept to around 1,000pF or less. If you have the Mitey Mike, you can use it to

Related Products

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The following products are available from *both* Liberty Instruments *and* Old Colony:

#SOF-IMP1B5G	IMP software disk 1 × 5¼" DS/DD	$ 49.95
#SOF-IMP1B3G	IMP software disk 1 × 3½" DS/DD	49.95
#PCBW-4	IMP double-sided PC board	39.95
#KW-4	Unassembled IMP parts kit, includes software (specify disk size) and PC board	249.00

The following products are available from Liberty Instruments *only*:

TLC274CN op amp
MAX190 A/D converter
6264 static RAM chip

Please inquire for prices

The following products are available from Old Colony *only*:

#KD-2	Unassembled Mitey Mike test microphone	149.00
#KMW-4	Unassembled IMP parts kit (as above) plus Unassembled Mitey Mike test microphone	389.00

Shipping (USA):
For orders of less than $50, please add $3 for shipping/handling. $50–99.99: $4. $100–199.99: $5. Greater than $200: $6. Outside the USA, please inquire.

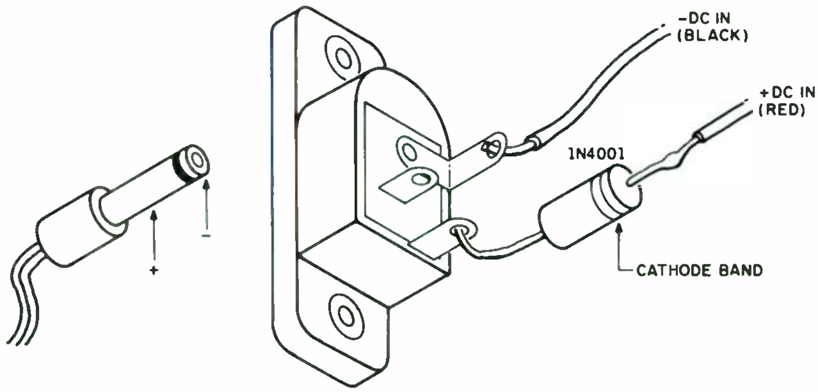

FIGURE 14: Wiring for DC power connector.

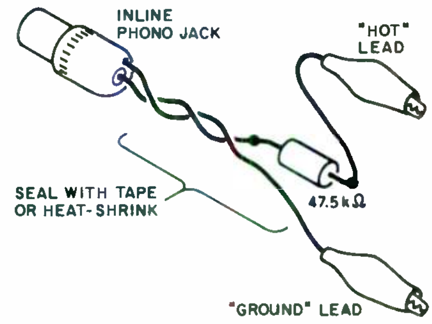

FIGURE 15: Probe construction.

drive the mike input through longer cables, as well as to provide lower electrical noise levels.

The probes are alligator clip leads fitted with 47.5kΩ series resistors in the "hot" lead for connection to speaker terminals or networks (*Fig. 15*). The leads should be about 6″ long and terminate in in-line phono jacks. Mark the clips so you'll know which one is ground, and connect that only to grounded points.

The series resistors serve two purposes: they allow the probe to operate at a high impedance yet feed a long, lower-impedance cable run, and they avoid potential damage to the IMP circuitry from amplifier output levels up to 40V. Do not attempt to use the IMP module probe inputs without the series resistors in the hot lines.

If you put the IMP board in a metal case (for best shielding from noise), tie the case to analog ground only, preferably from the microphone input connector shield. Do not connect either power supply connector terminal or the parallel port common leads directly to the case. Whether the board is put in a metal case or not, be sure the level-control metal bodies are connected to analog ground to avoid stray noise pickup.

In Part II, I'll explain the organization and operation of the IMP software.

Readers wishing to purchase an *assembled* IMP unit, with software, may indicate their nonbinding interest by circling #1497 on their Reader Service card.

QUASI-MONOTONIC VENTED ALIGNMENTS

BY RALPH GONZALEZ

A common problem facing loudspeaker designers is trying to use a woofer in a vented enclosure that is too small. This problem arises when you've already settled on a driver but must either use an existing enclosure or design an enclosure that is small enough to be aesthetically acceptable.

A few years back, G.R. Koonce produced tables reporting the Small-Margolis approximate alignments for nonoptimum enclosure sizes.[1] As usual, the driver parameters f_S (resonance frequency), Q_{TS} (magnitude at the resonance frequency), and V_{AS} (air volume equivalent to the suspension compliance) were required to use these tables. For a given driver Q_{TS}, Koonce's tables listed a range of $\alpha = V_{AS}/V_B$ values, reflecting a wide range of enclosure volumes (V_B). At each value of α, the recommended box tuning ratio ($h = f_B/f_S$) was listed, enabling you to tune the vent to the tuning frequency (f_B). The tables also listed the −3dB cutoff point and the amount of ripple in the frequency response of each nonoptimum design.

I've found Koonce's tables very useful over the past few years, since they give instant information on the expected error in the response when using a given driver in an existing nonoptimum enclosure. More recently, I've begun experimenting with several computer programs for designing vented enclosures. Most of these programs give a recommended f_B for nonoptimum boxes based on Small's alignments, optimizing power handling, or a combination of these and other factors. Computer-aided design has two advantages over table-based enclosure design: first, you may evaluate any tuning frequency (rather than relying on the recommended optimum); second, you get to see a predicted frequency response graph (rather than reducing ripple to a single number).

After some experimentation with these programs, I became convinced that you can use a too-small box without ripple effects if you change the tuning from the Small-Margolis recommendation. The shape of the resulting curve is different from that produced by the Small-Margolis alignments, but often has a deeper −6dB point. More important is the fact that the improved smoothness of the new curve will likely integrate better with the listening room, whereas the response peak in the Small-Margolis curve is often exacerbated to produce a subjective "boom."

ALIGNMENTS. A.N. Thiele presented a technique for designing vented loudspeakers, and discussed various alignments.[2] Richard Small's multipart paper extended Thiele's work to include the effects of enclosure losses.[3] Robert Bullock summarized these results and presented tables to assist the designer.[4]

The Small alignment for a driver with a Q_{TS} of 0.383 produces a fourth-order Butterworth (B4) high-pass response. The Butterworth response is termed "maximally flat," because it has the flattest pass band region of any of the possible alignments. Below the pass band, reponse falls at 24dB/octave. The response is monotonic: as frequency decreases, the reponse stays level or falls, but never rises.

For drivers with a Q_{TS} smaller than 0.383, the Small alignment follows the quasi-third-order Butterworth (QB3) filter, which also is monotonic. It falls at a more gentle rate than the B4 initially but increases in slope to 24dB/octave at frequencies well below the cutoff.

For drivers with a Q_{TS} greater than 0.383, the Small alignment produces a fourth-order Chebyshev (C4) high-pass response. This response is not monotonic. It has a ripple in the pass band such that with falling frequency, the response rises to a peak, drops back to the original level, rises to the height of the first peak, and finally falls off at 24dB/octave. Since the two peaks have the same height, the C4 alignment is said to provide equal ripple. The overall amount of ripple rises with increasing Q_{TS}: it is negligible up to 0.5 and reaches 0.5dB at 0.6.

Don Keele (then at Electro-Voice) used curve fitting to produce simple, unpublished equations approximating the relationships among Q_{TS}, h, and α for the Small alignments. Small and Margolis wrote programs for programmable calculators based on Keele's equations and an existing program by Dean Austin.[5] Koonce summarized and tabulated these results in his aforementioned article.

For a given driver using a nonoptimum box size, these programs recommend an approximate alignment. The recommended vent tuning for this alignment is the same as would be required for a Small alignment if the same size enclosure were used with a driver having optimum Q_{TS}. That is, the nonoptimum box tuning recommended by Small and Margolis depends only on alpha (α). The resulting frequency response curves do not fit the QB3/B4/C4 ideal and are usually nonmonotonic. They produce a peak or a dip in the frequency response depending on the Q_{TS} of the driver used.

ABOUT THE AUTHOR

Ralph Gonzalez lives in Wilmington, Delaware, with his wife Maureen and infant son, Brian. A Computer Science professor at Rutgers University in Camden, NJ, he received his Bachelors Degree in Mathematics from the University of Delaware, and his Doctorate Degree in Systems Engineering from the University of Pennsylvania. In addition to building speakers and listening to music, he enjoys playing bass guitar and writing audio-related computer software.

Table 1. QM4 alignments: Q_{ts}=.2

α	h	vented f_3/f_s	vented f_6/f_s	closed-box f_3/f_s	closed-box f_6/f_s
.2	.33	4.72	2.71	4.8	2.83
.22	.34	4.72	2.69	4.79	2.83
.24	.35	4.69	2.69	4.79	2.82
.26	.36	4.69	2.69	4.78	2.82
.28	.37	4.69	2.69	4.78	2.82
.3	.38	4.69	2.67	4.78	2.82
.32	.38	4.69	2.67	4.77	2.82
.34	.39	4.65	2.67	4.77	2.81
.36	.4	4.65	2.67	4.76	2.81
.38	.41	4.65	2.65	4.76	2.81
.4	.42	4.65	2.65	4.75	2.81
.42	.42	4.65	2.65	4.75	2.81
.44	.43	4.62	2.65	4.74	2.8
.46	.43	4.62	2.63	4.74	2.8
.48	.44	4.62	2.63	4.74	2.8
.5	.45	4.62	2.63	4.74	2.8
.55	.46	4.59	2.61	4.73	2.79
.6	.48	4.59	2.61	4.72	2.79
.65	.49	4.55	2.59	4.7	2.78
.7	.5	4.55	2.57	4.69	2.78
.75	.52	4.52	2.57	4.69	2.77
.8	.54	4.52	2.55	4.68	2.77
.85	.57	4.49	2.52	4.67	2.76
.9	.61	4.45	2.5	4.66	2.76
.95	.64	4.42	2.46	4.64	2.75
1	.67	4.39	2.43	4.63	2.75
1.1	.73	4.33	2.36	4.62	2.74
1.2	.8	4.27	2.28	4.59	2.73
1.3	.86	4.17	2.18	4.58	2.72
1.4	.92	4.11	2.06	4.56	2.71
1.5	.97	4.03	1.91	4.54	2.71
1.6	1.02	3.94	1.11	4.52	2.7
1.7	1.08	3.86	1.11	4.5	2.69
1.8	1.13	3.75	1.14	4.48	2.68
1.9	1.18	3.64	1.17	4.46	2.67
2	1.23	3.54	1.21	4.45	2.67
2.2	1.31	3.27	1.26	4.41	2.65
2.4	1.39	2.89	1.32	4.37	2.64
2.6	1.47	1.63	1.38	4.34	2.63
2.8	1.54	1.66	1.43	4.3	2.62
3	1.61	1.71	1.49	4.26	2.61
3.2	1.67	1.74	1.54	4.23	2.6
3.4	1.72	1.79	1.59	4.19	2.59
3.6	1.77	1.83	1.62	4.16	2.58
3.8	1.83	1.89	1.67	4.12	2.57
4	1.86	1.93	1.71	4.09	2.57
4.2	1.91	1.97	1.74	4.06	2.56
4.4	1.95	2	1.78	4.03	2.56
4.6	1.98	2.04	1.81	4	2.55
4.8	2	2.07	1.83	3.97	2.55
5	2.03	2.1	1.87	3.94	2.55

Small align.: α=7.78, h=1.94, f_3/f_s=2.53
B2 closed-box: α=11.50, f_3/f_s=3.54

Table 2. QM4 alignments: Q_{ts}=.25

α	h	vented f_3/f_s	vented f_6/f_s	closed-box f_3/f_s	closed-box f_6/f_s
.2	.31	3.64	2.09	3.73	2.21
.22	.32	3.64	2.09	3.73	2.21
.24	.33	3.64	2.07	3.72	2.2
.26	.34	3.61	2.07	3.71	2.2
.28	.35	3.61	2.07	3.71	2.2
.3	.36	3.61	2.06	3.71	2.2
.32	.36	3.59	2.06	3.7	2.2
.34	.37	3.59	2.06	3.69	2.19
.36	.38	3.59	2.04	3.69	2.19
.38	.39	3.56	2.04	3.69	2.19
.4	.4	3.56	2.03	3.68	2.18
.42	.4	3.56	2.03	3.67	2.18
.44	.41	3.54	2.01	3.67	2.18
.46	.41	3.54	2.01	3.67	2.18
.48	.42	3.54	2.01	3.66	2.18
.5	.42	3.54	2.01	3.65	2.18
.55	.44	3.51	1.98	3.65	2.17
.6	.5	3.46	1.94	3.63	2.16
.65	.55	3.41	1.9	3.62	2.16
.7	.6	3.36	1.85	3.61	2.15
.75	.64	3.31	1.79	3.59	2.15
.8	.69	3.27	1.72	3.58	2.14
.85	.72	3.22	1.66	3.57	2.14
.9	.77	3.17	1.54	3.56	2.14
.95	.8	3.1	1.42	3.55	2.13
1	.84	3.04	.86	3.54	2.13
1.1	.91	2.91	.9	3.51	2.12
1.2	.98	2.77	.94	3.49	2.11
1.3	1.04	2.57	.98	3.47	2.1
1.4	1.09	2.38	1.02	3.44	2.09
1.5	1.15	1.27	1.07	3.42	2.09
1.6	1.19	1.28	1.1	3.4	2.08
1.7	1.24	1.31	1.13	3.38	2.08
1.8	1.28	1.33	1.17	3.36	2.07
1.9	1.32	1.36	1.2	3.34	2.07
2	1.36	1.39	1.23	3.31	2.06
2.2	1.43	1.45	1.29	3.27	2.05
2.4	1.49	1.51	1.34	3.24	2.05
2.6	1.54	1.56	1.38	3.2	2.04
2.8	1.58	1.61	1.42	3.16	2.04
3	1.62	1.66	1.47	3.13	2.04
3.2	1.65	1.69	1.5	3.09	2.04
3.4	1.67	1.73	1.53	3.07	2.04
3.6	1.69	1.77	1.56	3.04	2.04
3.8	1.71	1.81	1.59	3.01	2.05
4	1.71	1.85	1.61	2.99	2.05
4.2	1.71	1.87	1.63	2.97	2.05
4.4	1.71	1.91	1.66	2.95	2.06
4.6 *	1.7	1.94	1.67	2.93	2.06
4.8	1.69	1.98	1.69	2.91	2.07
5	1.68	2.01	1.72	2.9	2.08

* Small align.: α=4.58, h=1.56, f_3/f_s=1.97
B2 closed-box: α=7.0, f_3/f_s=2.83

Table 3. QM4 alignments: Q_{ts}=.3

α	h	vented f_3/f_s	vented f_6/f_s	closed-box f_3/f_s	closed-box f_6/f_s
.2	.29	2.91	1.68	3	1.79
.22	.31	2.91	1.67	2.99	1.79
.24	.31	2.89	1.67	2.99	1.79
.26	.33	2.89	1.66	2.98	1.79
.28	.34	2.87	1.66	2.98	1.78
.3	.35	2.87	1.64	2.97	1.78
.32	.35	2.85	1.64	2.97	1.78
.34	.36	2.85	1.63	2.96	1.78
.36	.37	2.85	1.63	2.96	1.77
.38	.37	2.83	1.62	2.95	1.77
.4	.39	2.83	1.61	2.94	1.77
.42	.39	2.81	1.61	2.94	1.77
.44	.4	2.81	1.6	2.93	1.77
.46	.42	2.79	1.59	2.93	1.76
.48	.46	2.75	1.55	2.92	1.76
.5	.49	2.73	1.52	2.91	1.76
.55	.56	2.65	1.43	2.9	1.75
.6	.63	2.57	1.31	2.89	1.75
.65	.68	2.48	1.14	2.87	1.75
.7	.73	2.39	.72	2.86	1.74
.75	.78	2.31	.75	2.85	1.74
.8	.83	2.2	.78	2.83	1.74
.85	.86	2.09	.8	2.82	1.73
.9	.91	1.91	.83	2.81	1.73
.95	.94	1.72	.86	2.8	1.73
1	.97	1.04	.88	2.78	1.72
1.1	1.03	1.06	.92	2.76	1.72
1.2	1.09	1.1	.97	2.73	1.71
1.3	1.14	1.14	1.01	2.71	1.71
1.4	1.18	1.17	1.04	2.69	1.71
1.5	1.22	1.21	1.07	2.66	1.7
1.6	1.25	1.24	1.11	2.64	1.7
1.7	1.29	1.28	1.14	2.62	1.7
1.8	1.32	1.31	1.16	2.6	1.7
1.9	1.34	1.33	1.19	2.58	1.7
2	1.36	1.36	1.21	2.56	1.7
2.2	1.39	1.41	1.25	2.53	1.7
2.4	1.41	1.47	1.29	2.5	1.71
2.6	1.42	1.51	1.31	2.47	1.71
2.8 *	1.41	1.54	1.33	2.45	1.72
3	1.4	1.59	1.36	2.43	1.73
3.2	1.39	1.63	1.38	2.41	1.73
3.4	1.37	1.68	1.41	2.4	1.75
3.6	1.35	1.73	1.44	2.39	1.75
3.8	1.33	1.78	1.47	2.38	1.77
4	1.29	1.83	1.5	2.37	1.78
4.2	1.26	1.89	1.53	2.37	1.79
4.4	1.23	1.93	1.56	2.37	1.8
4.6 †	1.19	1.98	1.6	2.36	1.82
4.8	1.15	2.03	1.63	2.37	1.83
5	1.1	2.07	1.67	2.37	1.84

* Small align.: α=2.84, h=1.31, f_3/f_s=1.57
† B2 closed-box: α=4.56, f_3/f_s=2.36

The ripple value (R_H) was defined as the difference between this frequency response and that obtained using the same α with a driver whose Q_{TS} was optimum. (Specifically, R_H is the ratio of the actual driver Q_{TS} and the optimum Q_{TS}.) If the box is larger than that required for a Small alignment with the chosen driver, the Small-Margolis alignment produces a positive R_H, indicating a response peak.

If the box is smaller, the alignment produces a negative R_H, indicating a dip relative to the response that would occur if Q_{TS} had been optimum for this box. Incidentally, the f_3/f_S values reported in Koonce's tables are accurate only when R_H is near zero.

QUASI-MONOTONIC. The Butterworth and Chebyshev alignments are mathematically well understood and are characterized by the properties of maximum flatness and equal ripple. However, I was surprised to discover from experimenting with vented-design software that it is often possible to obtain a significantly lower −3dB point than that produced by the Small alignment. Also, if the box size is nonoptimum, it is usually possible to obtain a much smoother response than that produced by the Small-Margolis alignment. In fairness to Small and Margolis, they encourage users to experiment with departures from their recommended alignments.

I decided to come up with a new family of alignments that satisfied the "quasi-monotonic" requirement. These fourth-order quasi-monotonic (QM4) alignments are derived empirically rather than through mathematical analysis. As shown later, some driver-enclosure combinations have no QM4 alignments.

A quasi-monotonic curve is one whose output never rises significantly with falling frequency. To be specific, I require that as frequency falls, the output must never rise more than 0.25dB above the lowest level so far encountered. (Actually, it may rise more than 0.25dB as long as the resulting peak is below −12dB relative to the in-band response.) I selected this 0.25dB figure because a peak of this size should be inaudible. In many cases, restricting the peak to much less than 0.25dB would produce an alignment with very small h, resulting in a response similar to that of a closed box.

A Chebyshev curve having a small ripple would be monotonic. However, Small and Margolis used a different definition of ripple, measuring the deviation of a curve from the QB3, B4, or C4 curve of an optimum Small alignment. According to this definition, absence of ripple is neither necessary nor sufficient for monotonic response, which is why I am using the term "quasi-monotonic" instead of "low-ripple."

For a given Q_{TS} and α, I defined the QM4 alignment as the largest h (the highest tuning) that still produces a quasi-monotonic response. Lower tunings also generally satisfy the quasi-monotonic requirement but produce "droopier" curves. In a few circumstances, tuning slightly lower than the QM4 alignment may be found to lower f_3, but the potential improvement is only a fraction of a hertz.

QM4 TABLES. I wrote a computer program that tabulates the QM4 alignments for a range of Q_{TS} and α values. It takes a "brute-force" approach (running for several hours on a Macintosh II with a floating-point math accelerator). For each combination of Q_{TS}, α, and h, it must calculate a high-resolution frequency response curve using the Small-Margolis frequency response formula. (See "Limitations" later in this article.)

Table 1 lists the box tuning ratio (h) that results in a QM4 design for each box volume ratio (α), assuming a driver Q_{TS} of 0.2. It also lists the −3dB and the −6dB points resulting from this vented design and the −3dB and −6dB points for a closed-box (acoustic-suspension) design of the same size. The closed-box values are listed to demonstrate that in some cases (for example, when h is small, reflecting a low tuning frequency), there is little to gain by venting.

The −6dB point is listed because some of the QM4 alignments produce gently falling responses that have a relatively

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Table 4. QM4 alignments: Q_{ts}=.35

		vented		closed-box	
α	h	f_3/f_s	f_6/f_s	f_3/f_s	f_6/f_s
.2	.28	2.38	1.39	2.47	1.5
.22	.3	2.38	1.38	2.46	1.5
.24	.3	2.36	1.38	2.46	1.49
.26	.32	2.34	1.37	2.45	1.49
.28	.33	2.34	1.36	2.44	1.49
.3	.34	2.33	1.35	2.44	1.49
.32	.34	2.31	1.35	2.43	1.49
.34	.35	2.31	1.34	2.42	1.49
.36	.36	2.29	1.34	2.42	1.48
.38	.36	2.29	1.33	2.41	1.48
.4	.38	2.28	1.32	2.41	1.48
.42	.43	2.23	1.28	2.4	1.48
.44	.5	2.16	1.2	2.39	1.48
.46	.55	2.09	1.11	2.39	1.48
.48	.58	2.04	1.03	2.38	1.48
.5	.62	1.98	.61	2.38	1.48
.55	.69	1.85	.64	2.36	1.47
.6	.75	1.69	.68	2.35	1.47
.65	.8	1.47	.72	2.33	1.47
.7	.84	.86	.75	2.32	1.47
.75	.89	.88	.78	2.3	1.46
.8	.93	.91	.81	2.29	1.46
.85	.95	.94	.83	2.28	1.46
.9	.99	.96	.85	2.27	1.46
.95	1.02	.98	.88	2.26	1.46
1	1.04	1.01	.9	2.24	1.46
1.1	1.09	1.05	.94	2.22	1.46
1.2	1.13	1.09	.97	2.2	1.46
1.3	1.16	1.12	1	2.18	1.46
1.4	1.18	1.15	1.02	2.16	1.46
1.5	1.2	1.19	1.04	2.14	1.46
1.6	1.2	1.21	1.07	2.13	1.47
1.7	1.21	1.24	1.08	2.11	1.47
1.8 •	1.21	1.27	1.1	2.1	1.47
1.9	1.2	1.3	1.11	2.09	1.48
2	1.2	1.32	1.13	2.08	1.48
2.2	1.17	1.38	1.15	2.06	1.49
2.4	1.14	1.44	1.19	2.05	1.51
2.6	1.11	1.52	1.23	2.03	1.52
2.8	1.07	1.57	1.28	2.03	1.53
3 †	1.03	1.64	1.31	2.03	1.55
3.2	.98	1.71	1.36	2.03	1.56
3.4	.92	1.77	1.41	2.03	1.58
3.6	.85	1.83	1.47	2.03	1.6
3.8	.79	1.87	1.51	2.04	1.61
4	.71	1.93	1.54	2.05	1.63
4.2	.62	1.97	1.59	2.05	1.65
4.4	.51	2.01	1.62	2.06	1.66
4.6	.35	2.06	1.66	2.08	1.68
4.8	---	---	---	---	---
5	---	---	---	---	---

• Small align.: α=1.80, h=1.14, f_3/f_s=1.27
† B2 closed-box: α=3.08, f_3/f_s=2.02

Table 5. QM4 alignments: Q_{ts}=.4

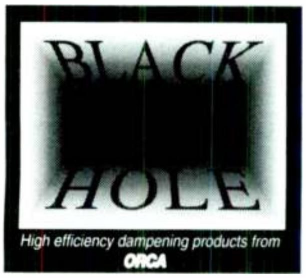
		vented		closed-box	
α	h	f_3/f_s	f_6/f_s	f_3/f_s	f_6/f_s
.2	.27	1.97	1.19	2.06	1.29
.22	.29	1.96	1.18	2.05	1.29
.24	.29	1.96	1.18	2.05	1.28
.26	.31	1.94	1.17	2.04	1.28
.28	.32	1.93	1.16	2.03	1.28
.3	.33	1.91	1.15	2.03	1.28
.32	.33	1.9	1.15	2.02	1.28
.34	.34	1.9	1.15	2.02	1.28
.36	.35	1.89	1.15	2.01	1.28
.38	.35	1.87	1.14	2.01	1.28
.4	.53	1.69	.92	2	1.28
.42	.59	1.59	.55	1.99	1.28
.44	.63	1.5	.57	1.99	1.28
.46	.67	1.38	.6	1.98	1.28
.48	.7	1.25	.62	1.98	1.28
.5	.72	1.06	.63	1.97	1.28
.55	.79	.77	.68	1.96	1.28
.6	.84	.79	.72	1.95	1.28
.65	.88	.83	.75	1.93	1.28
.7	.91	.85	.77	1.92	1.28
.75	.94	.88	.79	1.91	1.28
.8	.97	.9	.82	1.9	1.28
.85	.99	.93	.83	1.89	1.28
.9	1.02	.95	.85	1.88	1.28
.95	1.03	.97	.87	1.87	1.28
1	1.04	.99	.88	1.86	1.28
1.1 •	1.05	1.02	.9	1.84	1.29
1.2	1.05	1.05	.92	1.83	1.29
1.3	1.05	1.08	.94	1.82	1.3
1.4	1.03	1.12	.95	1.81	1.3
1.5	1.02	1.16	.96	1.8	1.31
1.6	1	1.21	.98	1.79	1.32
1.7	.98	1.26	1.01	1.78	1.32
1.8	.96	1.3	1.04	1.78	1.33
1.9	.93	1.35	1.07	1.78	1.34
2	.91	1.39	1.1	1.77	1.35
2.2 †	.84	1.48	1.16	1.77	1.37
2.4	.77	1.55	1.23	1.78	1.39
2.6	.7	1.62	1.29	1.78	1.4
2.8	.6	1.68	1.34	1.79	1.42
3	.48	1.74	1.39	1.8	1.44
3.2	.32	1.79	1.43	1.81	1.46
3.4	---	---	---	---	---
3.6	---	---	---	---	---
3.8	---	---	---	---	---
4	---	---	---	---	---
4.2	---	---	---	---	---
4.4	---	---	---	---	---
4.6	---	---	---	---	---
4.8	---	---	---	---	---
5	---	---	---	---	---

• Small align.: α=1.11, h=1.01, f_3/f_s=1.02
† B2 closed-box: α=2.13, f_3/f_s=1.77

Table 6. QM4 alignments: Q_{ts}=.45

		vented		closed-box	
α	h	f_3/f_s	f_6/f_s	f_3/f_s	f_6/f_s
.2	.27	1.66	1.04	1.75	1.13
.22	.28	1.64	1.04	1.74	1.13
.24	.28	1.64	1.04	1.74	1.13
.26	.3	1.63	1.03	1.73	1.13
.28	.31	1.62	1.02	1.72	1.13
.3	.32	1.61	1.02	1.72	1.13
.32	.32	1.6	1.01	1.71	1.13
.34	.33	1.59	1.01	1.71	1.13
.36	.34	1.57	1.01	1.7	1.13
.38	.61	1.18	.54	1.7	1.13
.4	.67	.65	.57	1.69	1.13
.42	.7	.67	.6	1.69	1.13
.44	.73	.68	.62	1.68	1.13
.46	.76	.7	.64	1.68	1.14
.48	.78	.72	.65	1.67	1.14
.5	.8	.73	.67	1.67	1.14
.55	.85	.77	.7	1.66	1.14
.6	.89	.8	.73	1.65	1.14
.65	.91	.83	.75	1.64	1.14
.7 •	.92	.85	.76	1.63	1.15
.75	.92	.86	.77	1.62	1.15
.8	.93	.88	.78	1.62	1.15
.85	.92	.9	.78	1.61	1.15
.9	.92	.92	.79	1.61	1.16
.95	.91	.94	.79	1.6	1.16
1	.9	.96	.8	1.59	1.17
1.1	.88	1.03	.82	1.59	1.18
1.2	.86	1.09	.86	1.58	1.18
1.3	.82	1.16	.9	1.58	1.19
1.4	.79	1.22	.94	1.58	1.2
1.5 †	.76	1.28	.99	1.58	1.21
1.6	.71	1.33	1.04	1.58	1.22
1.7	.68	1.37	1.08	1.58	1.23
1.8	.63	1.41	1.12	1.58	1.24
1.9	.58	1.45	1.15	1.59	1.25
2	.52	1.5	1.19	1.59	1.27
2.2	.36	1.56	1.25	1.6	1.29
2.4	---	---	---	---	---
2.6	---	---	---	---	---
2.8	---	---	---	---	---
3	---	---	---	---	---
3.2	---	---	---	---	---
3.4	---	---	---	---	---
3.6	---	---	---	---	---
3.8	---	---	---	---	---
4	---	---	---	---	---
4.2	---	---	---	---	---
4.4	---	---	---	---	---
4.6	---	---	---	---	---
4.8	---	---	---	---	---
5	---	---	---	---	---

• Small align.: α=.69, h=.90, f_3/f_s=.83
† B2 closed-box: α=1.47, f_3/f_s=1.57



A better speaker damping material...

If you've been building speakers for some time, you know how much guesswork goes with speaker damping and stuffing. The choices seem endless: fiberglass, wool, Dacron, flat foam, convoluted foam, felt, tar, plus various "magic" compounds that you're invited to brush or pour into your new cabinets. Everyone has their own recipe, and who knows if it's a recipe for disaster? Or what effects the vapors emitted by these chemicals might have on the glues that bond your woofer surround to its cone and chassis? In this era of costly, space-age drivers and computer-assisted design, we think such risks are totally unacceptable. So we went to work to find the ideal solution.

The problems are fairly well-known: a driver transforms electrical energy into mechanical energy. This mechanical energy is transformed into acoustical energy which is radiated to the outside of the cabinet - the useful front wave - and to the inside - the sometimes-useful back wave. Unfortunately, it is also transmitted though the frame of the driver to the cabinet itself, which acts as a very large "cone" of very small excursion. This means that the spurious resonances and vibrations of the cabinet have to be controlled in a predictable and reproduceable way. That's how we came to BLACK HOLE 5 and the BLACK HOLE PAD.

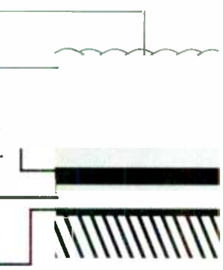
First, THE PAD. It's a thin (1/16 inch) black flexible viscoelastic damping material (filled vinyl copolymer) with maximum performance between 50 and 100 degrees F (we hope that that covers the temperature range of your listening room) and excellent flame resistance - it meets UL94 V-O. Thanks to its outstanding damping characteristics, THE PAD will dramatically reduce the vibration energy stored in the walls to which it is applied.

Easy to cut and apply, THE PAD has a pressure-sensitive adhesive back: simply peel off the release paper and press hard onto a clean surface. You can use THE PAD on just about anything you suspect of vibrating: driver frames, thin panels like car doors, and, of course, the walls of your speaker cabinets. And it can be used to recess a driver without using a router: just laminate enough layers to match the thickness of the driver frame and apply to the front baffle. Finally, it is the ideal material for "constrained layer" wall construction, where two panels are laminated on each side of a damping material for optimum transmission loss. Because THE PAD has a fine grain leather finish, you can wrap an entire cabinet exterior and give it an attractive appearance at the same time!

For applications which require **maximum damping, isolation and absorption,** we've developed BLACK HOLE 5. One and 3/8" thick, BLACK HOLE 5 is a high-loss laminate that provides optimum acoustical damping performance. It consists of five layers:

Thin diamond-pattern embossing, densified with a polyurethane film surface. This unique surface layer dramatically improves the performance of the whole acoustical system, especially the lower mid-range and mid-bass frequencies where simple acoustical foam loses its effectiveness.

One-inch deep polyester urethane foam, structurally optimized for acoustical damping. Highly effective at "soaking" maximum sound energy with minimum thickness.



Barrier septum, 1/8 inch thick. Made of limp flexible vinyl copolymer loaded with non-lead inorganic fillers, it is a "dead wall" that isolates the vibrations in the walls of your cabinet from the vibrations created inside the enclosure.

Polyester urethane flexible open-cell foam, 1/4 inch thick. Thanks to special vibration-isolation characteristics, it decouples the vibrating structure (the wall) from the rest of the damping system, thus optimizing performance.

High-loss vibration damping material, same as The Pad. It is strongly bonded to the cabinet wall with pressure sensitive adhesive.

These layers are laminated using an adhesive-free mechanical and thermal process, thus optimizing performance and eliminating the risk of solvent fume damage. BLACK HOLE 5 can be used in any enclosure, as well as for acoustical panels to improve the characteristics of your listening room. *YOU PROVIDE THE MUSIC; BLACK HOLE FIVE WILL TAKE CARE OF THE NOISE!*

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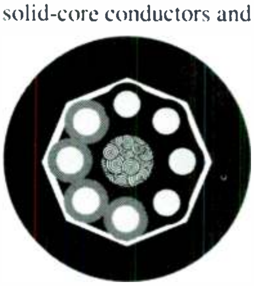
AX-ON (Greek axon, axis): that part of a nerve cell through which impulses travel away from the cell body. AXON 8 speaker cable combines outstanding design features with component quality usually associated with the most expensive cable. With eight AXON 1 solid-core conductors and utilizing mylar/ polypropylene construction, AXON 8 offers outstanding performance for amp-speaker connections and perfectionist internal speaker wiring. Our superb AXON 1 AWG 20 solid core conductor is also available separately. Oxygen-free and 99.997% pure, it is ideal for most internal wiring applications.



Outer insulation: UL approved TPE
Cable geometry: non interleaved spiral
Individual conductor insulation: 105 degree Celsius, UL approved PVC
Cable equivalent gauge: total - AWG 11, 2 conductors - AWG 17, 4 conductors - AWG 14
Individual conductors: solid core AWG 20 copper, long-grain and ultra-soft, free of all contaminants and oxygen.
Cable core: crushed polypropylene
Inner envelope: mylar film

Reader Service #29

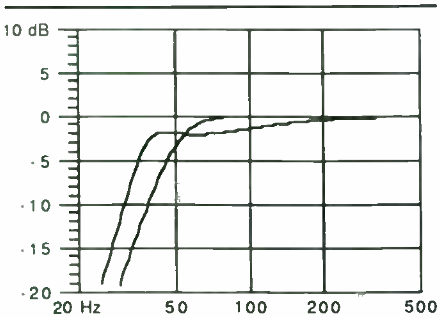


FIGURE 1: Small alignment: α = 1.11 (top), and QM4 alignment with lowest f_3: α = 0.55 (bottom), for Q_{TS} = 0.4.

Continued from page 26

high −3dB point but a much lower −6dB point. (I omitted the usual −10dB figure because a speaker contributes little useful bass at its −10dB point.) At the bottom of *Table 1* is the optimum Small alignment (QB3 in this case) and the closed-box alignment that results in a second-order Butterworth (B2) maximally flat response.

Tables 2-9 are similar. Where possible, the value for α used for the optimum Small or closed-box alignment is indicated with an asterisk or a dagger. The tuning (h) for the optimum Small alignment usually appears close to that for the corresponding QM4 alignment.

• For the higher-Q tables, some of the values for α cannot produce a QM4 design, as indicated by "---." This happens when the box is so small that even a closed box (with no vent contribution) results in a peak >0.25dB. Note that the B2 closed box represents the smallest enclosure (largest α) that still produces a perfectly monotonic (0dB peak) response. Also note that the B2 closed box has the best closed-box −3dB extension for a given Q_{TS}.

COMPARISONS. *Figures 1, 2,* and *3* compare the predicted response for quasi-monotonic and Small-Margolis alignments using the same driver. The driver's parameters are Q_{TS} = 0.4 and f_S = 50Hz.

Figure 1 compares the response using the optimum Small alignment (α = 1.11) with the QM4 alignment that gives the lowest −3dB point, as indicated by *Table 5* (α = 0.55). Note that this choice of QM4 alignment requires a box that is twice as large as the optimum Small alignment. The shape of the Small alignment is approximately that of the maximally flat B4. If you can tolerate a larger enclosure and the "droopy" shape of the resulting QM4 alignment, however, you obtain a much lower −3dB point. (As mentioned in the "Limitations" section, this comparison doesn't take into account the relative power-handling ability of these alignments.)

Figure 2 compares alignments using the same box size (α = 2.2; i.e., the box is about half that required for a Small alignment). This happens to be the optimum closed-box size for this driver. The Small-Margolis alignment (h = 1.28) gives a 2dB peak. The QM4 alignment (h = 0.84) gives a more nearly flat response in exchange for a higher −3dB point. Note, however, that the −6dB point for the QM4 design is similar to that of the Small-Margolis alignment. This gentler roll-off will almost certainly work better in most listening rooms.

Figure 3 assumes that α = 0.42 (i.e., the box is more than twice as large as is required for the Small alignment). Again, the Small-Margolis alignment (h = 0.76) gives significant ripple. The QM4 alignment (h = 0.59) gives a flatter response with a higher −3dB point

Continued on page 30

Table 7. QM4 alignments: Q_{ts}=.5

α	h	vented f_3/f_s	vented f_6/f_s	closed-box f_3/f_s	closed-box f_6/f_s
.2	.26	1.42	.94	1.51	1.02
.22	.27	1.41	.94	1.5	1.02
.24	.28	1.4	.93	1.5	1.02
.26	.29	1.39	.94	1.49	1.02
.28	.3	1.38	.93	1.49	1.02
.3	.31	1.37	.93	1.48	1.03
.32	.31	1.37	.92	1.48	1.03
.34	.59	.97	.51	1.48	1.03
.36	.68	.62	.57	1.47	1.03
.38	.72	.65	.6	1.47	1.03
.4	.76	.67	.62	1.47	1.03
.42	.78	.69	.63	1.46	1.03
.44	.8	.71	.65	1.46	1.04
.46 •	.8	.71	.65	1.45	1.04
.48	.81	.72	.66	1.45	1.04
.5	.82	.73	.67	1.45	1.04
.55	.82	.74	.67	1.44	1.04
.6	.82	.76	.68	1.44	1.05
.65	.8	.78	.68	1.43	1.05
.7	.79	.82	.68	1.43	1.06
.75	.78	.86	.69	1.43	1.06
.8	.77	.92	.7	1.42	1.07
.85	.74	.98	.72	1.42	1.07
.9	.73	1.03	.75	1.42	1.08
.95	.71	1.07	.79	1.42	1.08
1 †	.69	1.11	.83	1.42	1.09
1.1	.64	1.18	.9	1.42	1.1
1.2	.6	1.23	.96	1.42	1.11
1.3	.54	1.29	1.01	1.43	1.12
1.4	.47	1.33	1.05	1.43	1.13
1.5	.4	1.37	1.09	1.44	1.15
1.6	.29	1.41	1.13	1.44	1.16
1.7	.11	1.44	1.15	1.45	1.17
1.8	---	---	---	---	---

• Small: α=.46, h=.80, f_3/f_s=.72, R=.1 dB
† B2 closed-box: α=1.0, f_3/f_s=1.41

Table 8. QM4 alignments: Q_{ts}=.55

α	h	vented f_3/f_s	vented f_6/f_s	closed-box f_3/f_s	closed-box f_6/f_s
.2	.26	1.24	.86	1.32	.94
.22	.27	1.24	.86	1.32	.94
.24	.27	1.23	.86	1.32	.94
.26	.29	1.22	.86	1.31	.95
.28	.3	1.21	.86	1.31	.95
.3	.3	1.21	.86	1.31	.95
.32	.66	.59	.55	1.31	.95
.34 •	.72	.63	.59	1.31	.95
.36	.74	.64	.59	1.3	.96
.38	.73	.64	.59	1.3	.96
.4	.73	.64	.59	1.3	.96
.42	.72	.65	.59	1.3	.96
.44	.71	.65	.59	1.3	.96
.46	.7	.66	.58	1.3	.97
.48	.69	.68	.58	1.29	.97
.5	.68	.71	.58	1.29	.97
.55	.67	.82	.58	1.29	.98
.6	.65	.91	.6	1.29	.98
.65 †	.62	.97	.67	1.29	.99
.7	.6	1.01	.73	1.29	1
.75	.57	1.07	.79	1.29	1
.8	.55	1.1	.83	1.29	1.01
.85	.51	1.14	.87	1.29	1.01
.9	.49	1.16	.9	1.3	1.02
.95	.45	1.19	.93	1.3	1.03
1	.41	1.21	.96	1.3	1.03
1.1	.31	1.27	1.01	1.31	1.05
1.2	.15	1.31	1.04	1.31	1.06
1.3	---	---	---	---	---
1.4	---	---	---	---	---
1.5	---	---	---	---	---
1.6	---	---	---	---	---
1.7	---	---	---	---	---
1.8	---	---	---	---	---

• Small: α=.35, h=.73, f_3/f_s=.64, R=.3 dB
† B2 closed-box: α=.65, f_3/f_s=1.29

Table 9. QM4 alignments: Q_{ts}=.6

α	h	vented f_3/f_s	vented f_6/f_s	closed-box f_3/f_s	closed-box f_6/f_s
.2	.25	1.12	.82	1.19	.88
.22	.26	1.12	.82	1.19	.89
.24	.27	1.11	.82	1.19	.89
.26	.28	1.11	.82	1.19	.89
.28 •	.29	1.11	.82	1.18	.89
.3	.62	.55	.51	1.18	.9
.32	.6	.55	.5	1.18	.9
.34	.59	.57	.5	1.18	.9
.36	.59	.75	.5	1.18	.9
.38 †	.57	.83	.49	1.18	.9
.4	.57	.85	.49	1.18	.91
.42	.56	.88	.49	1.18	.91
.44	.54	.92	.52	1.18	.91
.46	.53	.94	.63	1.18	.92
.48	.52	.96	.67	1.18	.92
.5	.5	.98	.72	1.18	.92
.55	.47	1.02	.77	1.19	.93
.6	.44	1.06	.82	1.19	.94
.65	.39	1.1	.85	1.19	.94
.7	.35	1.12	.88	1.19	.95
.75	.29	1.15	.91	1.2	.96
.8	.22	1.18	.94	1.2	.97
.85	.1	1.2	.96	1.21	.97
.9	---	---	---	---	---
.95	---	---	---	---	---
1	---	---	---	---	---
1.1	---	---	---	---	---
1.2	---	---	---	---	---
1.3	---	---	---	---	---
1.4	---	---	---	---	---
1.5	---	---	---	---	---
1.6	---	---	---	---	---
1.7	---	---	---	---	---
1.8	---	---	---	---	---

• Small: α=.27, h=.68, f_3/f_s=.59, R=.5 dB
† B2 closed-box: α=.39, f_3/f_s=1.18

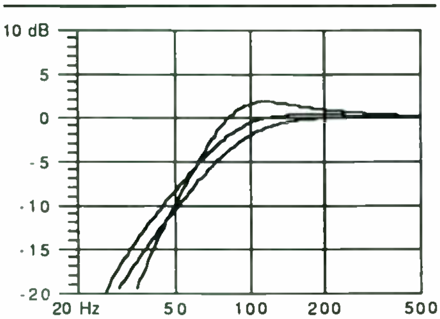


FIGURE 2: Small-Margolis (top), QM4 (middle), and closed-box (bottom) alignments for $Q_{TS} = 0.4$, $\alpha = 2.2$ (box too small).

Continued from page 28

but a lower −6dB point. Tuning the box even lower will help reduce the "shelving" evident in the QM4 curve but will bring the response even closer to that of a closed box. In this case, it is not clear whether the QM4's smoothness is more important than the extra "fullness" of the Small-Margolis curve.

VENT VARIABLES. If you decide to use these tables for enclosure design, Bullock's formula for vent design is:

$$L = \frac{1.463 \times 10^7 \times r^2}{(f_B^2 \times V_B)} - r \times 1.463$$

where L is the vent length and r is the vent radius. (This formula contains a typographical error in Bullock's *SB* 4/80 article.)

Use units consistently: L and r are in inches, and V_B is in cubic inches. You should choose a large radius (an inch or more) to avoid audible turbulence in the vent. (See "Limitations.") For more information on vented-box construction, see the many excellent *SB* articles on this topic by Bullock, Koonce, and others.

LIMITATIONS. Observe these several caveats when using the QM4 tables:

I used the approximation $f_{SB} = f_S$, which can produce up to 5% error in some circumstances.

I assumed a box loss parameter (Q_L) of 7, a typical value. This can produce about 3% error if you use an extremely large or extremely small enclosure.

You must interpolate for values of Q_{TS} between those listed. Linear interpolation of h will typically produce less than 5% error. Let Q_1 and Q_2 be the closest values to your driver Q_{TS}, and let h_1 and h_2 be the h values given in the Q_1 and Q_2 tables for your choice of α. Then using linear interpolation, you should tune the box to

$$h = h_1 + (h_2 - h_1) \times \frac{Q_{TS} - Q_1}{Q_2 - Q_1}$$

I calculated the values in the tables without considering power handling. A different tuning may be better if power handling is critical. For example, it appears that using an oversized box and a low tuning frequency to extend the bass response (*Fig. 1*) usually reduces low-frequency power handling. Several computer programs for vented enclosure design show the power-handling ability of a design.

Very low values of h imply a low tuning frequency (f_B). This sometimes results in impractical vent length–diameter combinations. In such cases, the vented alignment usually has little advantage over a like-sized closed box.

CONCLUSIONS. The QM4 alignments are one of many alternative alignments, none of which can be said to be "optimum" in an absolute sense. The quasi-monotonic property must be weighed against the maximally flat and equal ripple properties of the Thiele-based alignments.

If your box size and choice of driver are both fixed, note that the Small-Margolis alignments appear to have more fullness in the bass for medium-Q to high-Q drivers in oversized boxes, without becoming too peaky (*Fig. 3*). For undersized boxes, the QM4 alignments help you to obtain comparable −6dB extension without suffering the Small-Margolis alignments' boomy response (*Fig. 2*).

If you are trying to decide on the best box size for a given driver, consider the following. For a given Q_{TS}, the QM4 tuning (h) corresponding to Small's optimum α (indicated by an asterisk in the tables) is usually the highest QM4 tuning of any α. That is, Small's optimum box volume usually produces the highest-tuned quasi-monotonic curve. Larger enclosures require lower tuning, producing droopy responses with superior extension. Undersized enclosures don't suffer from droopiness but lack some extension. The venerable Small alignment straddles these alternatives.

Finally, if you have a box and want to find the best driver, consider the following. Suppose you have several drivers with similar V_{AS} but a range of Q_{TS} values to choose from. If you choose the driver whose Q_{TS} yields the optimum Small alignment for your V_{AS}/V_B ratio, you will usually get the highest f_B and the deepest f_3 among the quasi-monotonic alternatives having the same α.

I hope this article will inspire you to design enclosures based on nonstandard alignments. If you eventually move on to a computer-aided vented-enclosure design approach, you'll be able to compare alternative alignments with great precision. You'll also gain the ability to create alignments that best meet your requirements and integrate well with your room.

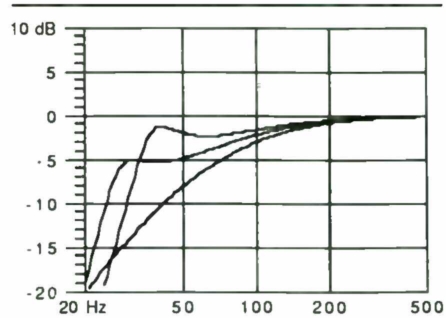


FIGURE 3: Small-Margolis (top), QM4 (middle), and closed-box (bottom) alignments for $Q_{TS} = 0.4$, $\alpha = 0.42$ (box too big).

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Fs	57	67	43	32	24	20	17	18
RMS Power:	60	60	60	100	150	150	150	100
System Power:	150	150	150	175	200	200	200	150
Sensitivity:	88	88	89	90	89	89.6	89	92
Voice coil:	25	25	25	40	50	50	50	50
Magnet mass:	240	344	240	794	1134	1700	1700	1134
SD meters:	.008	.008	.0143	.022	.0345	.0545	.0545	.0855
Dcr:	5.5	5.6	5.6	4.7	6.45	6.1	3.11	4.6
Inductance:	.62	.7	.68	.98	1.7	1.6	2.0	2.3
Xmax:	2	2	3	4	7.68	7.68	10.54	5
Mmd:	7.24	6.5	11.9	26.4	57	89	73	119
BL:	4.97	5.07	5.61	6.3	12.15	13.22	7.8	15.866
Qms:	1.659	1.81	3.052	6.74	3.978	5.458	5.1	6.677
Qes:	.628	.652	.636	.441	.420	.452	.481	.288
Qts:	.455	.479	.526	.414	.38	.418	.44	.276
Vas:	9	7	28	56	111	242	380	561
Range:	57-9k	67-9k	43-7k	32-4k	24-2k	20-1k	17-500	18-1k
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Part II

WHAT MAKES YOUR ROOM HI-FI?

BY JOSEPH SALUZZI

Last time, I discussed small room acoustics and how room size and shape affect the sonic character of a listening room. On the basis of wave theory, I selected a standard rectangular room with the dimensions 21′2″ × 16′4″ × 8′9″.

In Part II, I cover some of the construction details of the room. In addition, I address surface treatment and furnishings and discuss more theory on how to build an ideal sound room.

ROOM CONSTRUCTION. For the construction of the west wall of my listening room, I used standard ½″ Sheetrock and 2″ × 4″ studs on 16″ centers. I built the south wall to enclose and isolate my analog and stereo equipment, as shown in *Fig. 1*. This staggered arrangement of two-by-fours with insulation fill provides up to 52dB of sound isolation, or a 16dB improvement over standard Sheetrock construction.[1]

I topped this 4′ × 16′ area with a double ceiling consisting of plywood, 1′ of air space, insulation, and then Sheetrock. I carefully measured and configured the south and west walls to conform exactly to my dimensions.

I constructed the listening area drop ceiling with "egg crate" panels, as shown in *Fig. 2*. These acoustically transparent units are readily available from home improvement centers. I used them to hide service lines and the Helmholtz resonators that are bolted to the ceiling. To help camouflage as much as possible, I painted everything above the panels black, including the Sheetrock. For better sound isolation, 3½″ unbacked insulation between the joists was used. I meticulously taped and mudded the wall and ceiling Sheetrock to make the surfaces as airtight as possible.

Although I constructed the room and its adjoining analog and storage area in about a year, the project was far from complete. The sound room was unfurnished, and the walls were bare. The room exhibited a noticeable slap echo, and it was highly reverberant. I was tempted to put down a rug, furnish it, and call it a day, but after a short recess, I began Phase 3.

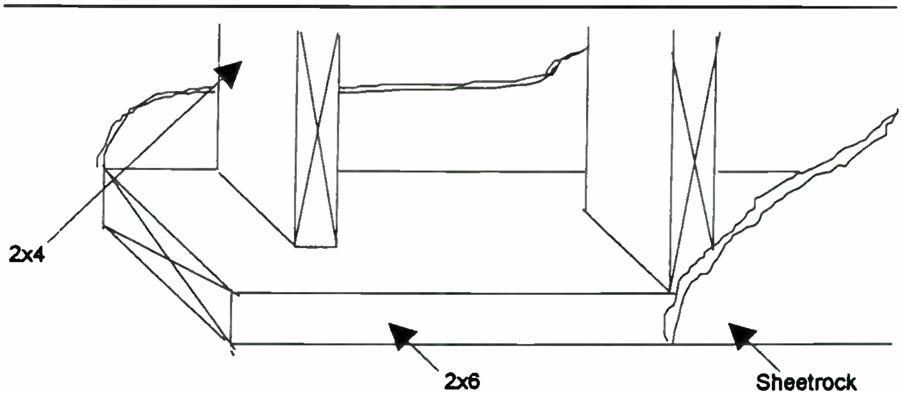

FIGURE 1: South wall construction for better sound isolation; STC 42–52dB with insulation.

REVERBERATION. Everyone has experienced the effect of reverberation on sound quality at some time. For example, when we placed our extension speakers outside for a barbecue, the sound was thin, dry, and lifeless, especially if the speakers were positioned at a distance from any boundary. In this instance, what we heard was essentially all the direct sound.

At the other extreme, when I was in high school, I recall singing with my friends inside a highly reverberant highway underpass. The sound was full and rich and had bass. Reverberation made us sound much better than we really were. In this case, my friends and I heard mostly reflected sound.

For sound applications, however, an overly reverberant room can be a detriment, as reflections tend to destroy intelligibility. In highly reverberant fields, a sound may travel by many paths, since it may consist of numerous reflections off walls and other surfaces. As a result, it arrives at the listener's ears at different times, which smears sounds, reducing clarity. The design of a good listening environment should enable a careful balance of direct versus reflected sound to provide full, pleasing sound without sacrificing definition.

REVERBERATION TIME. When a loudspeaker is excited and produces a

ABOUT THE AUTHOR

Joseph Saluzzi is employed as a director of marketing in the chemical industry. He received his M.S. and B.S. in chemistry from Long Island University and his M.B.A. from Fairleigh Dickinson University. He developed an interest in audio in 1968 when he built several Heath and Dyna products. He also has constructed a pair of Bozak Concert Grands. He resides in Atlanta with his wife and their four children.

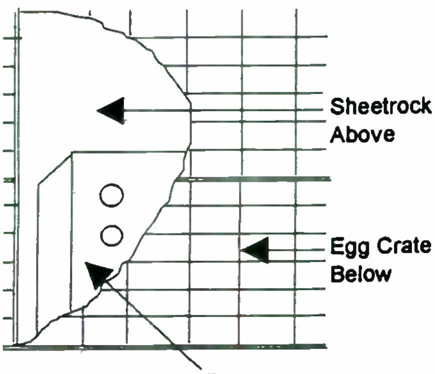

FIGURE 2: "Egg crate" panels hiding the Sheetrock ceiling.

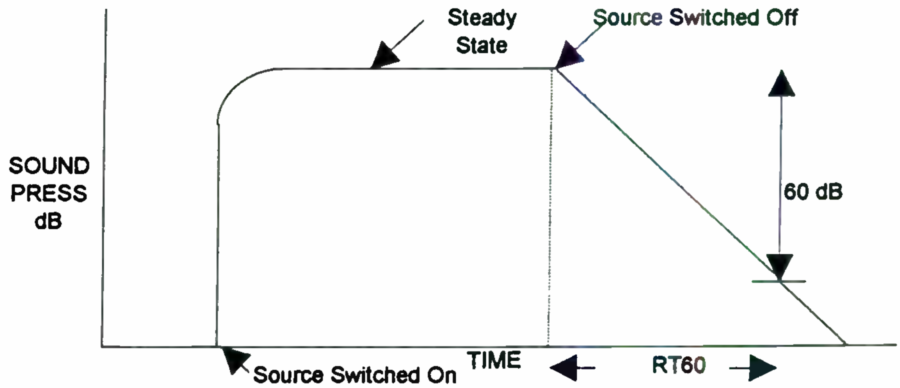

FIGURE 3: Graphic definition of reverberation time.

given sound within a listening environment, the sound pressure increases until it approaches a steady state. If the sound source is switched off, the sound pressure decays in a finite period of time. By definition, in a well-mixed reverberant field, the "reverberation time," or RT_{60}, is the time interval, in seconds, required for the reverberant soundfield to decay by 60dB.

Figure 3 is a simplification of what is actually observed. RT_{60} may exhibit more than one slope and may involve less linear decay. For small rooms or ones that audiophiles are most likely to encounter, reverberation time has no meaning because there is no well-mixed reverberant field, only a series of early reflected energy. Under these conditions, the term "decay rate" (D), given in dB/seconds, is more appropriate:

$$D = \frac{60(dB)}{RT_{60}}$$

When I began my project in 1985, reverberation time was considered the most important acoustic characteristic of a listening space. Today researchers regard reverberation time as one of several important physical parameters defining the acoustics of a listening environment. For small rooms, these parameters may include room resonances, the initial time delay gap (ITD), and decay rate or early reflections. (Refer to Part I, *SB* 6/92, for a discussion of room resonances.)

Regarding reverberation time and its decay rate, applying the concept of reverberation time to small spaces has been legitimately criticized, since reverberation equations are based on the assumption that a random soundfield exists. At the risk of stretching theory too far, we need to evaluate the absorption of a room and to adjust its perceived "liveness." Classically, this is done by calculating reverberation time.

In 1898, Wallace C. Sabine, a physics professor at Harvard University (and designer of Boston's Symphony Hall), discovered the mathematical relationship among the absorptive property of an acoustical material, room size, and reverberation time.[2] This fundamental equation is still widely used by acoustical engineers to calculate the acoustic properties of rooms and surfaces.

$$RT_{60} = \frac{0.049 \times V}{S\alpha}$$

TABLE 1

ABSORPTION COEFFICIENTS

MATERIALS	COEFFICIENTS, Hz 125	250	500	1000	2000	4000
Brick,unglazed	0.03	0.03	0.03	0.04	0.05	0.07
Brick,unglazed,painted	0.01	0.01	0.02	0.02	0.02	0.03
Carpet,heavy on concrete	0.02	0.06	0.14	0.37	0.6	0.65
Same,on 40 oz hairfelt or foam rubber	0.08	0.24	0.57	0.69	0.71	0.73
Same,with impermeable latex backing	0.08	0.27	0.39	0.34	0.48	0.63
Concrete block,coarse	0.36	0.27	0.39	0.34	0.48	0.63
Concrete block,painted	0.1	0.05	0.06	0.07	0.09	0.08
Fabrics:						
Light velour,10 oz per sq yd hung straight,in contact with wall	0.03	0.04	0.11	0.17	0.24	0.35
Medium velour,14 oz per sq yd draped to half area	0.07	0.31	0.49	0.75	0.7	0.6
Heavy velour,18 oz per sq yd draped to half area	0.14	0.35	0.55	0.72	0.7	0.65
Floors:						
Concrete or terrazzo	0.01	0.01	0.015	0.02	0.02	0.02
Linoleum,asphalt,rubber or cork tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Wood	0.15	0.11	0.1	0.07	0.06	0.07
Wood parquet in asphalt on concrete	0.04	0.04	0.07	0.06	0.06	0.07
Glass:						
Large panes of heavy plate glass	0.18	0.06	0.04	0.03	0.02	0.02
Ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04
Gypsum Board, 1/2" nailed to 2 x 4's 16 o.c.	0.29	0.1	0.05	0.04	0.07	0.09
Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02
finish on tile or brick	0.013	0.015	0.02	0.03	0.04	0.05
Plaster, gypsum or lime,rough finish on lath	0.14	0.1	0.06	0.05	0.04	0.03
Same,with smooth finish	0.14	0.1	0.06	0.04	0.04	0.03
Water Surface,as in a swimming pool	0.008	0.008	0.013	0.015	0.02	0.025
Building Insulation,3 1/2 " R-11						
insulation toward sound	0.35	0.95	1.2	0.55	0.35	0.25
paper toward sound	0.3	0.85	1.1	0.95	0.95	1.15

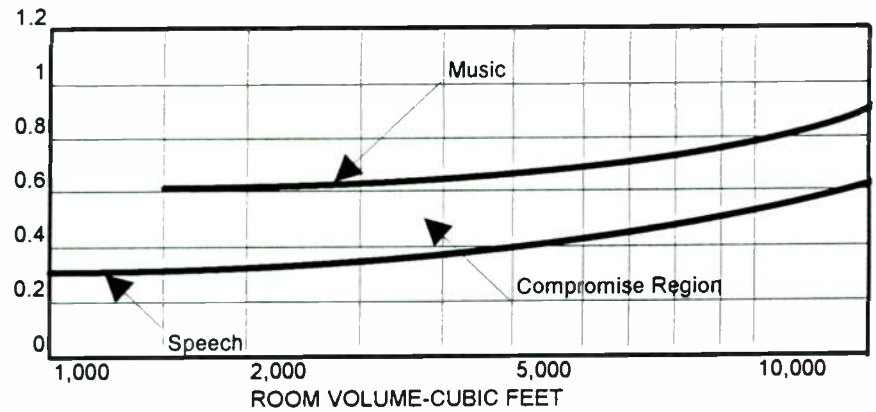

FIGURE 4: Optimum reverberation time for small listening rooms and studios.

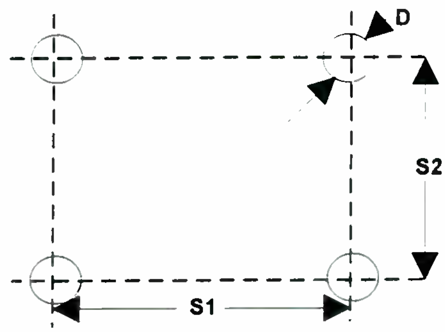

FIGURE 5: Calculations of the perforation percentage.

where:

V = room volume in ft.³
S = total surface area of room in ft.²
α = average sabin absorption coefficient

I will discuss the absorptive properties of acoustic materials and their absorption coefficients later, but for now let's say that this variable is related to a substance's ability to absorb sound. It is frequency-dependent and can vary from zero for poor absorbers to one for ideal absorbers. The quantity $0.049 \times V$ is actually the mean free path, or the average distance a sound travels between reflections. $S\alpha$ is the total number of absorption units, or sabins of absorption, in the room, and is evaluated by the following relationship:

$$S\alpha = S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3$$

where:

S_1 = area of material 1
α_1 = absorption coefficient of material 1
S_2 = area of material 2
α_2 = absorption coefficient of material 2
S_3 = area of material 3; α_3 = absorption coefficient of material 3

Sabine's equation is valid in "live" rooms because it is based on the mean distance between encounters or reflections; this mean free path is statistically meaningful as the number of encounters increases. Although other equations attempt to correct for very high absorption, Sabine's equation is the one most widely accepted by acousticians. In addition, most of the compiled data on absorption coefficients for various acoustic materials is derived from Sabine's relationship.

REVERBERATION TIME. As I mentioned earlier, too much or too little reverberation is undesirable for audio applications. The question is, how much is appropriate? As might be expected, literature on ideal reverberation time conflicts, since it is dependent on room size and application. For speech, where clarity is paramount, a short reverberation time is best. For music, a longer reverberation time may be better.

To complicate the matter further, optimum reverberation time depends on the type of music you listen to. For example, percussive music requires less reverberant fields because it comprises transients and musical notes of short duration. For symphonic music, which may involve massive, sustained sound, more reverberant fields may be appropriate.

Everest has taken an empirical approach and suggests a curve of acceptable reverberation times.[3] His findings, based on his experiences and those of other researchers, are shown in *Fig. 4*. According to Everest, these results are not definitive, but following this curve will result in reasonably optimized and usable conditions.

Fortunately for audiophiles, less dissension exists regarding how reverberation time should vary with frequency. Most researchers recommend uniform or constant reverberation times as frequency varies. This means all the frequency components of a signal fade away at the same time. Theoretically, I should furnish and treat my 3,025 ft.³ listening room to obtain uniform reverberation times (actually, uniform decay rates) over the audible frequency range; an acceptable value would range between 0.35–0.6 seconds.

SOUND ABSORPTION. The sound-absorbing property of a substance is described by its absorption coefficient, α. The absorption coefficient of an acoustic material is defined as the ratio of the total energy incident on a surface minus the energy reflected from the surface to

Continued on page 36

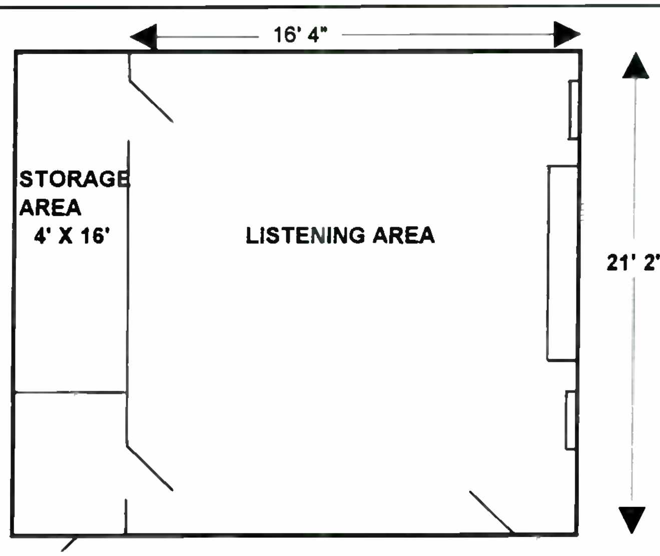

FIGURE 6: Schematic of the unfurnished living room.

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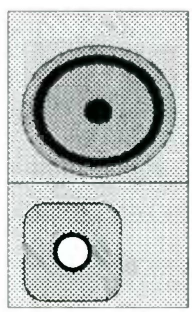

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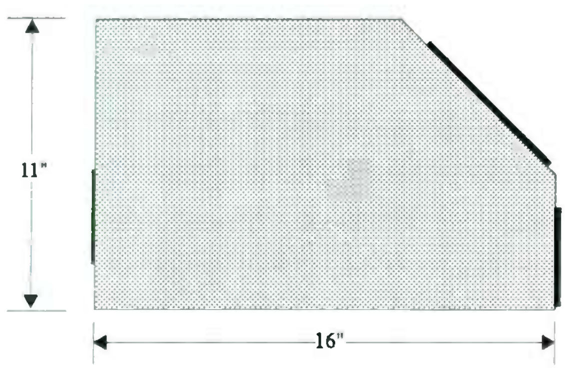

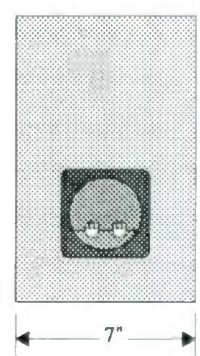

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Continued from page 34

the energy incident upon the surface. It can vary from zero, for highly reflective substances, to one, for highly absorptive materials. The absorption coefficient is a function of frequency; you should specify a table or curve of absorption coefficients versus frequency to describe the acoustic properties of a substance completely. By convention, most data is listed for the frequencies 125, 250, 500, 1k, 2k, and 4kHz.

The experimental procedure for obtaining absorption coefficients for a substance is described in *ASTM Standard C423-77*. The standard calls for a specimen size of at least 72 ft.^{2}, which is the customary size. The test room must be very hard and able to support a reverberant or diffuse soundfield close to ideal.

First, measure the reverberation time of the room at the previously mentioned frequencies without the specimen. Bring the test material into the room, and repeat the experiment. Calculate the absorption coefficient from Sabine's equation and the difference in reverberation times. Complete tables of coefficients for various materials commonly found in interiors are readily available in various books on architectural acoustics. I have included a summary of this data in *Table 1*.[4]

ACOUSTIC MATERIALS. The process of sound absorption occurs when acoustic energy is converted to some other form of energy, usually heat. The three major means of converting acoustic energy include porous absorbers, diaphragmatic absorbers, and resonant or reactive absorbers.

Porous absorbers are common and can be fibrous, soft materials or hard substances that are porous or contain cavities. Examples include carpeting, sofas and cushions, draperies, insulation, and acoustic ceiling tiles. When a sound wave encounters this type of material, air moves within the spaces surrounding the pores or fibers. This results in frictional energy, generation of heat, and loss of acoustic energy. Porous absorbers are generally more effective in controlling high frequencies.

Diaphragmatic absorbers are panels arranged with air cavities behind them. They tend to vibrate at a natural frequency, which is given by the mass of the panel and the depth of the air space, as in the following equation:[5]

$$f_o = \frac{170}{\sqrt{m \times d}}$$

where:

f_o = frequency in Hz
m = mass of panel in lb./ft.^{2}
d = depth of air space in inches

Sound is absorbed at this frequency as the panel oscillates because of the friction of the fibers within the panel and the friction of the air molecules behind the panel. Some common materials that

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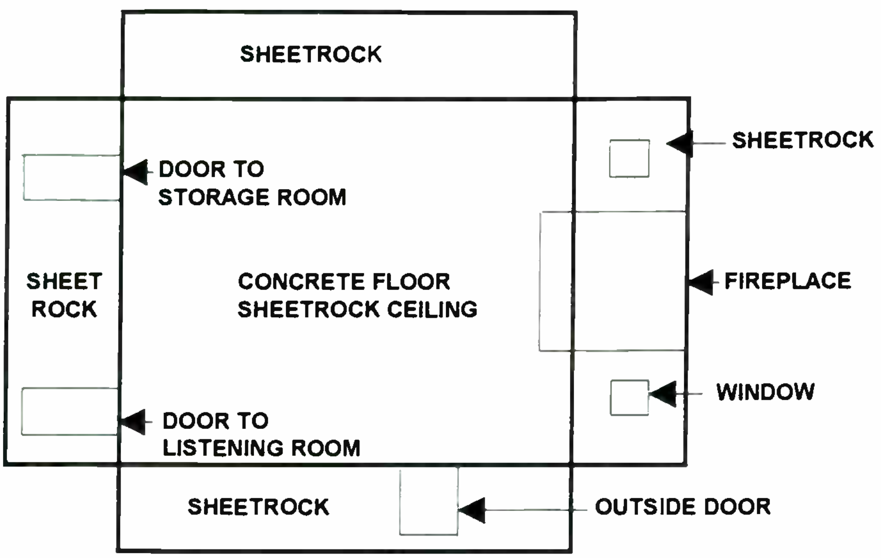

FIGURE 7: Construction materials for the listening area.

SURFACE MATERIAL	AREA SQ FT
SHEETROCK AREA:	
WALLS	509.2
CEILING	345.7
FIREPLACE BRICK	58.3
DOORS (3)	63
FLOOR CONCRETE	345.7
WINDOWS(2)	25.7

TABLE 2

REVERBERATION CALCULATIONS

MATERIAL		FHZ 125		250		500		1000		2000		4000	
	S sq ft.	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Walls sheetrock 1/2'	509.20	0.14	71.29	0.07	35.64	0.04	20.37	0.04	20.37	0.07	35.84	0.09	45.83
Ceiling sheetrock 1/2"	345.70	0.14	48.40	0.07	24.20	0.04	13.83	0.04	13.83	0.07	24.20	0.09	31.11
Fireplace brk	58.30	0.03	1.75	0.03	1.75	0.03	1.75	0.04	2.33	0.05	2.92	0.07	4.08
Doors(3)	63.00	0.28	17.64	0.22	13.86	0.17	10.71	0.09	5.67	0.10	6.30	0.11	6.93
Floor concrete	345.70	0.01	3.46	0.01	3.46	0.02	6.91	0.02	6.91	0.02	6.91	0.02	6.91
Windows(2)	25.70	0.35	9.00	0.25	6.43	0.18	4.63	0.12	3.08	0.07	1.80	0.04	1.03
TOTAL ABS SABINS			151.53		85.33		58.20		52.20		77.77		95.89
			125		250		500		1000		2000		4000
REVERB TIME SEC			0.98		1.74		2.55		2.84		1.91		1.55

Unfurnished room, volume 3,025 ft.^{3}

Continued from page 36

may be used as panel absorbers include plywood, hardboard, common paneling and Sheetrock. Because of their mass, panel absorbers are effective at absorbing lower frequencies.

Resonant or reactive absorbers, often called Helmholtz resonators, are perforated hardboard or plywood panels that are spaced away from the wall. Each hole acts as the neck of a Helmholtz resonator, and the air inside the cavity acts as a spring. As the sound strikes the hole, it tends to make the air within the cavity vibrate at a certain frequency, which is given by the following equation:[6]

$$f_o = 200 \times \sqrt{\frac{p}{d \times t}}$$

where:

f_o = frequency in Hz
p = perforation percentage (hole area ÷ panel area × 100)
t = effective hole length in inches, with a correction factor applied [(panel thickness) + (0.8) × (hole diameter)]
d = depth of air space in inches

Figure 5 shows how the perforation percentage is derived. Its equation is:

$$p = \pi \frac{\frac{D^2}{4}}{(S_1 \times S_2)} \times 100$$

where:

D = diameter of hole in inches
S_1 = distance on center between horizontally adjacent holes in inches
S_2 = distance on center between vertically adjacent holes in inches

Perforated panel absorbers can provide exceptional absorption properties at very low frequencies. Their cavities are generally filled with acoustic material, such as building insulation, to broaden their absorption bands.

Another type of resonant absorber is the slat resonator, which uses very closely spaced slats over a cavity. The mass of the air in the spaces between the slats acts as a spring to form a resonant system that is comparable to a Helmholtz resonator.

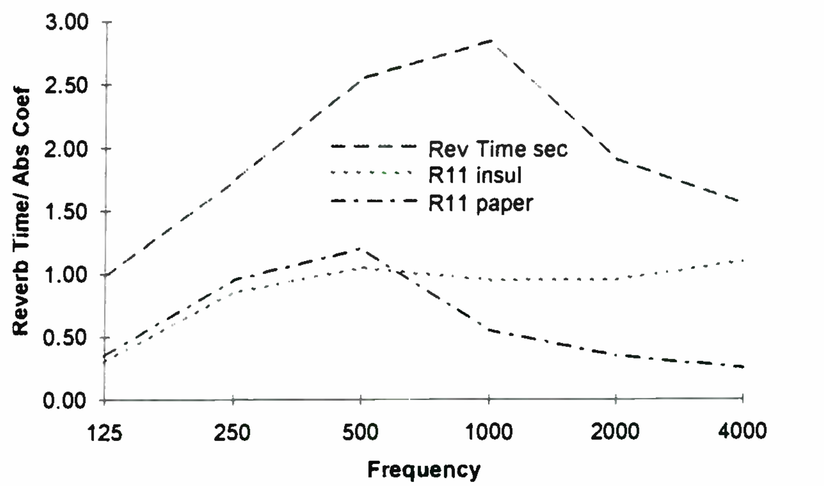

FIGURE 8: Reverberation times and absorption coefficients versus frequency for the listening room.

TABLE 3

INITIAL READINGS (UNFURNISHED ROOM)

FREQUENCY	READINGS										
	1	2	3	4	5	6	7	8	9	10	Average
63	1.01	1.05	1.49	1.23	1.21	0.96	1.12	1.39	1.26	1.14	1.19
125	1.08	1.36	0.99	1.23	1.31	1.35	1.04	1.03	1.21	1.05	1.17
250	1.12	1.15	1.17	1.22	1.09	1.46	1.11	1.16	1.06	1.26	1.18
500	1.04	1.26	1.35	1.44	1.49	1.26	1.19	1.15	1.13	1.15	1.25
1000	1.44	1.57	1.44	1.37	1.39	1.53	1.31	1.44	1.51	1.43	1.44
2000	1.31	1.4	1.71	1.16	1.31	1.19	1.47	1.31	1.38	1.35	1.36
4000	1.37	1.27	1.32	1.16							1.28
8000											

CALCULATIONS.

Figures 6 and *7* show the configuration, dimensions and materials used to build the unfurnished room and its adjacent storage area. *Table 2*, which follows Everest's format, demonstrates the calculation process for reverberation times at various frequencies. I compiled these results with the help of a spreadsheet program. This approach not only saves a significant amount of time, but it also allows me to investigate various scenarios.

As a first approximation, I used the same absorption coefficients for the walls and ceiling. I approximated the coefficients for the wooden doors from values published for wood paneling.

As an example, let's calculate by hand the reverberation time at a frequency of 125Hz. Substitute the room volume (3,025 ft.³) and the sum of the individual absorptions for each material (Sα = 151.5) in Sabine's equation:

$$RT_{60} = \frac{0.049 \times 3{,}025}{151.5} = \frac{148.225}{151.5} = 0.98 \text{ sec.}$$

The reverberation time for each frequency may be calculated in a similar fashion.

As expected for an unfurnished room, the reverberation times were high and not uniform over the frequency range. My goal was to reduce the times to conform with Everest's ideal curve.

Figure 8 shows the reverberation times versus frequency for the room. I also have plotted and superimposed the absorption coefficients of 3½″ building insulation. The coefficients for this material vary depending on whether the insulation or paper side faces the sound. Insulation is inexpensive and readily available, and should be considered a viable surface treatment.

TEST MEASUREMENT.

RT_{60} calculations are at best first-order approximations and should not be used for accurate work. Sabine's equation is valid under ideal or diffuse soundfields, which is a rare condition in real-world listening environments.

In addition, published absorption coefficients are sometimes contradictory. For example, the Sheetrock I used has at least three values at 125Hz—0.1, 0.14,

Continued on page 40

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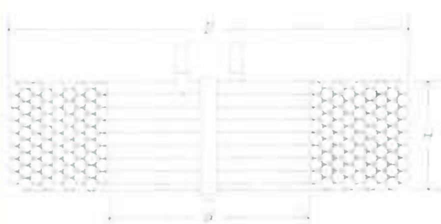

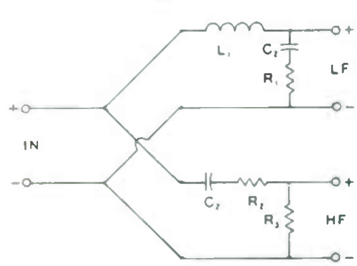

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Continued from page 38

and 0.29. This 200% variance will have a profound impact on calculated results. Sometimes a coefficient may have values that exceed 1.0, which implies that the material absorbs more than is theoretically possible, or that there may not be any published coefficients for the material in question.

To measure reverberation times, I used the Acoustilog Model 232A reverberation timer. This instrument is convenient to use and provides 2% basic accuracy as well as 10ms resolution. Its built-in pink noise generator generates bands centered at 63, 125, 250, 500, 1k, 2k, 4k, and 8kHz. This sound source yields more accurate and reproducible results than pure tones or sine waves. Pink noise is broadband and is more apt to excite fully any room modes that do not exactly coincide with the test frequencies.

I took measurements using the setup in *Fig. 9*. The Model 232A has two settings—30dB for more accurate results and 20dB when background noise is a problem and the recommended >100dB sound-pressure levels are not possible or desirable. In either case, the unit's digital display reads the RT_{60} directly.

After I smoked one of my KEF tweeters using the 30dB setting, I used the 20dB setting and, as the manufacturer suggested, compensated by taking ten readings for each measurement. After my initial setback, I used the robust Radio Shack Mach II speaker until I replaced the tweeters and was comfortable with the test procedure. The test method cancels component and loudspeaker coloration and is independent of equipment.

Measurements with the reverberation timer are straightforward. After calibrating the Send and Receive controls and setting the averaging filters, select the test frequency. Press the Reset button and the Count button, in that order, to send out the signal. Finally, record the reading.

For most experiments, I took readings at four different microphone locations, including the listening position, to determine the diffusion level and the precision of the results. Theory implies that reverberation time is independent of location in perfectly diffuse soundfields, which is valid only in larger environments.

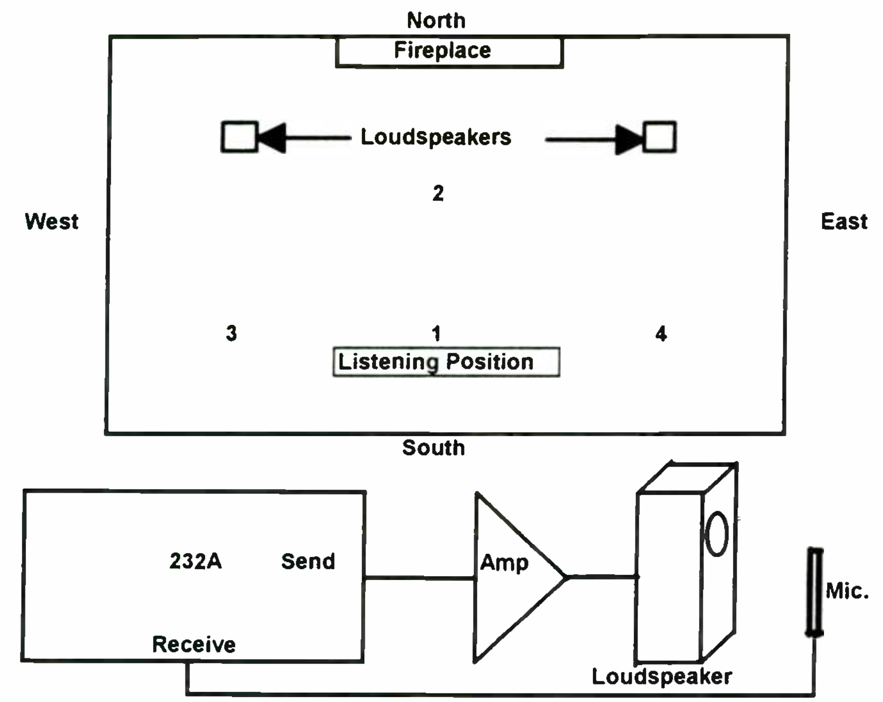

FIGURE 9: Microphone positions and equipment setup for reverberation times.

TABLE 4

REVERBERATION TIMES AT POSITION 1

FREQUENCY	READINGS										
	1	2	3	4	5	6	7	8	9	10	Average
63	1.34	1.47	1.44	1.18	1.37	1.47	1.57	1.29	1.51	1.26	1.39
125	0.79	0.79	0.54	0.6	0.67	0.6	0.58	0.54	0.47	0.47	0.61
250	0.69	0.76	0.61	0.83	0.61	0.9	0.71	0.78	0.93	0.6	0.74
500	0.66	0.59	0.61	0.63	0.66	0.65	0.62	0.63	0.54	0.63	0.62
1000	0.62	0.59	0.69	0.62	0.63	0.62	0.62	0.67	0.6	0.63	0.63
2000	0.63	0.54	0.54	0.65	0.68	0.6	0.58	0.65	0.53	0.62	0.60
4000	0.56	0.64	0.62	0.61	0.61	0.59	0.64	0.58	0.61	0.63	0.61
8000	0.53	0.63	0.61	0.62	0.6	0.6	0.56	0.6	0.61	0.56	0.59

Source: left speaker. 72 ft.^{2} insulation at random.

INITIAL RESULTS. *Table 3* includes some of the early results for the unfurnished room. Take care to note that I took only four readings at 4kHz; the fifth reading fried my tweeter. The calculated values in *Table 3* do not agree with the experimental results except that both show an increase in RT_{60} with frequency and a peak at 1kHz.

After the initial tests, I went to the home improvement center and purchased two rolls of paper-lined R-11 building insulation. I proceeded to treat the room surfaces in a random fashion by temporarily attaching varying lengths of this material. I laid some on the floor and above the "egg crate" panels. According to Everest, applying all the absorbent material on one or two surfaces does not result in a diffuse condition.[7] In addition, it seems that the absorbent material is more effective in patches. For years I had wrongfully accepted the premise that a listening room's floor

Continued on page 43

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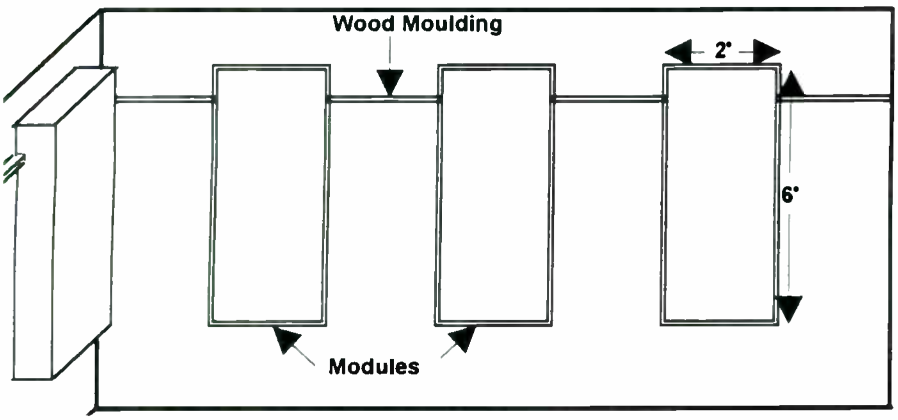

FIGURE 10: Modules housing acoustic material and Helmholtz resonators. These devices hang on wooden molding and may be moved.

cant. For example, a 2′ section of 16″ insulation has a surface area of 2.4 ft.[2] Its edges have a total surface of 1.9 ft.[2]

The data in *Table 4* is encouraging. I discovered that insulation is effective for controlling reverberation time. Now I have at least two problems. How do I control the lower frequencies? How do I use insulation without creating an unsightly mess? One approach is to use sound-absorbing modules, as shown in *Fig. 10*. These modules, used in some recording studios, are rectangular boxes containing acoustic material, typically insulation. The front is usually covered with some attractive cloth that allows the sound to pass through. The modules

Continued on page 69

Continued from page 40

must be carpeted for smooth frequency response and good bass.

Using Sabine's equation, I calculated that I needed about 144 ft.[2] of insulation, or an additional 144 sabins to bring the 1kHz RT_{60} down to an acceptable 0.6 seconds. This material has an absorption coefficient of about 1.0 at this frequency. After I installed 72 ft.[2] of insulation in patches, I set up the microphone at the listening position and placed the Mach II at the normal loudspeaker locations.

Table 4 summarizes the results at microphone position 1 with the left speaker as the sound source. Apparently, only half the calculated material is required to obtain the desired results. At first glance, it may appear that Sabine's theory is not valid. However, when small patches of acoustic material are used, the contribution of its edges can be signifi-

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Part III

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By now, your cabinets should be ready for finishing with plywood veneer. But first, we thought we'd get the systems up and running so you can get an idea of how they're going to sound.

DRIVER MOUNTING.

40. Before mounting the woofer, loosely fill any gaps in the woofer chamber with the last few handfuls of fiber. Acousta-Stuf fibers can touch the magnet, but not the cone. Wool fibers should be held well back from the woofer.

41. Mounting the drivers is relatively straightforward. We used machine screws and T-nuts. The woofer requires #10 pan-head screws; the mid takes #8 pan-head screws; the tweeter uses #8 flat-head screws. Many trips to the hardware store would be saved if manufacturers would only settle on a common mounting screw. Match your thread sizes: a 10/24 T-nut will not work with a 10/32 bolt. We recommend a gasket between each driver frame and the baffle.

42. You can either use slip-on clips or solder the lead-in wires directly to the speaker lugs. The lugs on earlier runs of the Focal mid-driver are small and delicate, so be cautious when attaching clips. Older model Focal tweeter lugs may loosen under prolonged heating—solder swiftly!

CROSSOVERS. Each crossover (CO) mounts externally in its own box. Our original boxes were about 12″ square and 3″ high, but these dimensions are not critical. We suggest you size the board and stuff it with electrical components before designing an enclosure. *Photo 1* shows the stuffed board from A&S. For mounting ease, we ran all wires on top. Twelve-position, European-style barrier strips (Radio Shack cat. #274-679) make an excellent wiring termination inside the box (*Photo 2*). If finish material (such as plastic laminate) is planned, apply it before any holes are drilled.

43. Two pieces of ¼″ tempered hardboard serve well as component boards. Lay out the CO parts to see how big an area you need, then cut the boards to size. Leave enough room at each corner for mounting screws. Fasten the components and the barrier strips to the board with hot glue, then solder all the components according to the schematic diagram (*Fig. 1*). Coils set on edge to

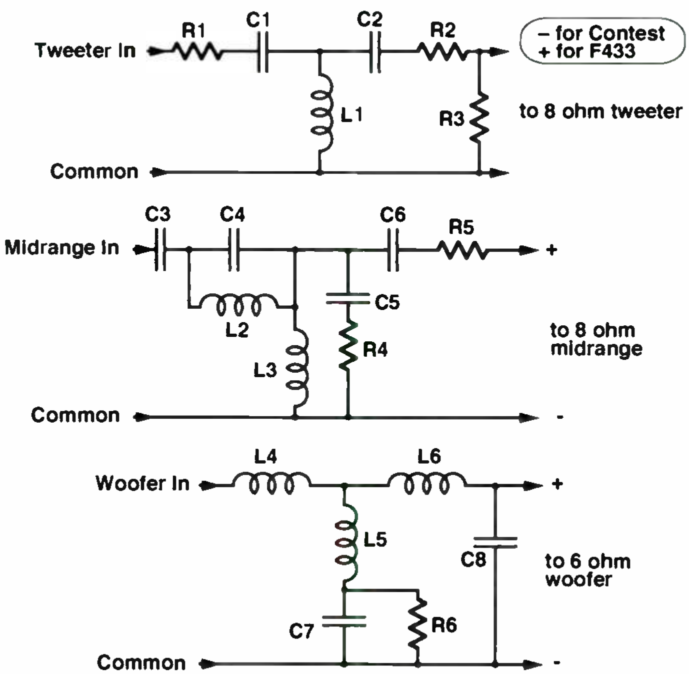

FIGURE 1: Crossover schematic.

ABOUT THE AUTHORS

Robert J. Spear holds a Master of Science degree in music from Ithaca (NY) College and began his musical career as a bass player and teacher. Since 1980, he and his wife have lived near Washington, DC, where they hand-build violins, violas, and cellos for professional musicians. Bob is an active member of the Catgut Acoustical Society, an international organization devoted to researching the acoustics of violin family instruments. An avid audiophile, his current preoccupation is trying to coax deep bass from small woofers.

Alexander F. Thornhill holds a degree in electrical engineering from the University of Maryland. He is semi-retired from a career at the Naval Research Lab in Washington, DC. Alex designed the radio transmitter for the Vanguard satellite, and has also worked on radio navigation devices and AF filters, among other things. His interest in audio predates stereo, and he divides his listening time between his "old" mono system with an RCA duo-cone speaker mounted in a Karlson enclosure with his "new" system, an AR-1 paired with an AR-3.

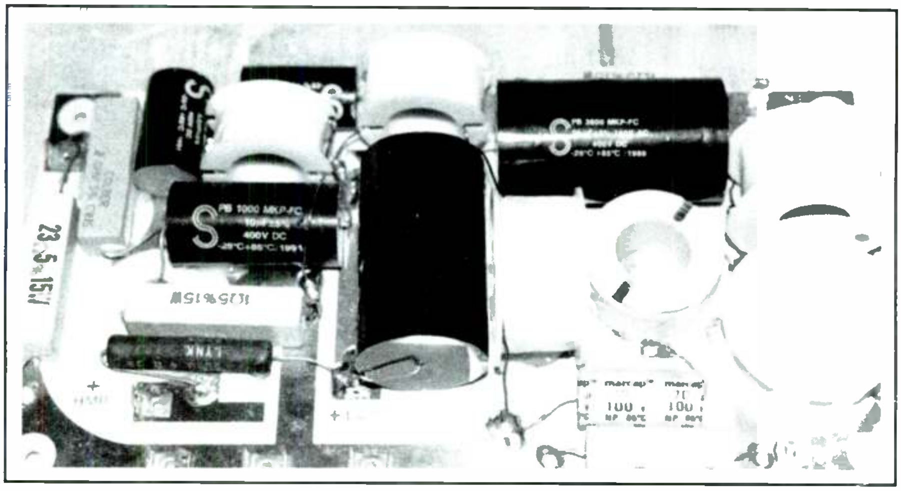

PHOTO 1. A&S crossover uses common ground.

showing the placement of the speaker spring clips with jumpers for a single pair from the amp.

46. Carefully lay out the location of terminal mounting screws and lugs on the CO enclosure. A drill press is highly recommended for this step. When drilling, clamp a piece of scrap wood to the face of the work to keep the Formica™ from splintering. For larger holes, bore a pilot hole first using a small diameter bit, then a medium bit, and finish with a full-sized bit. This will also help to reduce splintering.

47. The crossover design requires the tweeter to be wired out of phase. Reverse the leads inside the crossover enclosure to avoid confusion.

48. Make a group of three wire pairs of suitable length to use between the crossovers and the speaker enclosures. We like #14 AWG heater wire because of its very flexible insulation. Color code both ends of all wires to show their polarity and which driver they feed. Secure the bundles with cable ties or split plastic cable tubes called "looms" (*Photo 4*), which are available in auto parts stores.

reduce coupling should have their form flanges filed flat and, in addition to the glue, be fastened to the board with heavy twine or nylon ties.

44. Placement of external input and output terminals is not critical, but units should be consistent with each other. The proximity of the crossover's input and output groups is also not critical, but mark them plainly.

45. As the schematic shows, each portion of the network has its own ground. This requires three output terminal pairs to the speakers and three input pairs from the amplifier. *Photo 3* is the outside of an unfinished competition enclosure,

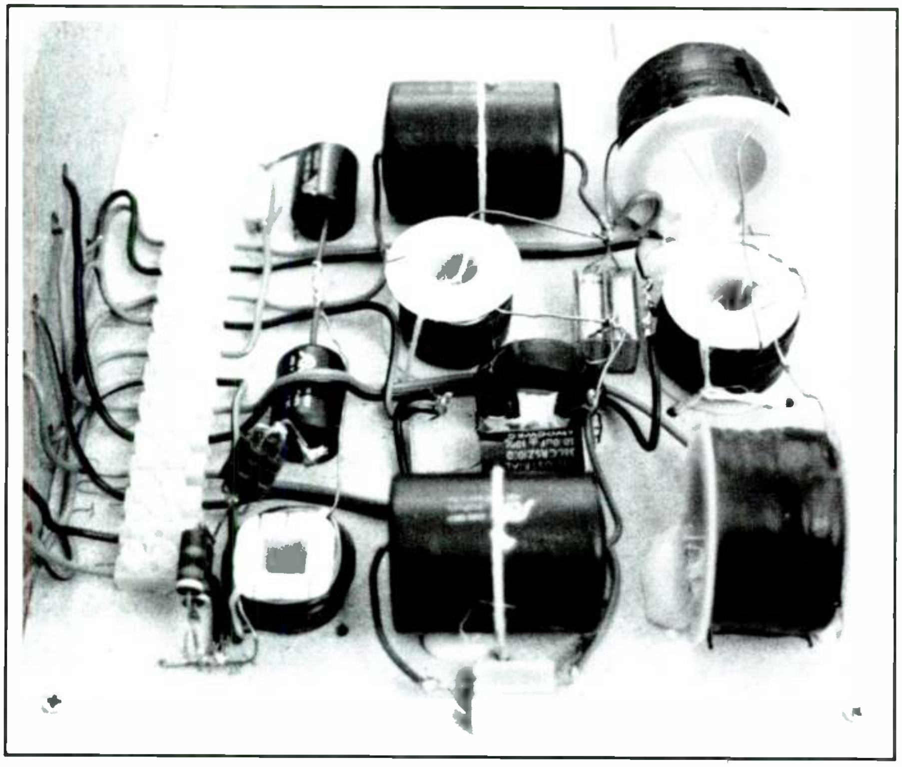

PHOTO 2: Contest crossover showing wiring at barrier strip. This unit has a separate ground for each filter.

TAKE FIVE. Temporarily screw on the final side panel and enjoy your speakers for a while. Now's the time to break in the drivers, adjust the stuffing ratio, or make any tweaks you'd like, because it will be difficult to do later.

You probably admired Mark Florian's beautiful oak-finished enclosures ("A High-Quality Speaker Cabinet," *SB* 3/92, p. 14), but lack the wherewithal to accomplish the tongue-in-groove and biscuit joinery. Similar results can be had using simple hand tools and edge-joins and, in the process, minor goofs in the particleboard joinery can be hidden.

You will need six pieces of ½-inch oak-veneer plywood: four to fit the sides, two for the tops, plus about 38 lineal feet (lf) of ½" × ½" solid oak trim for edges. The oak trim dimensions must be large enough to compensate for any misfit pieces and still "stand proud" about 1/16" on both exposed sides. *Figure 2* shows how to arrive at the dimension needed if your front baffle is too narrow. If all MDF edge joins are flush, the trim can be an exact ½" × ½" (actual dimension). Commercial ½-inch oak-veneer plywood is generally 7/16" thick. If yours is thicker, adjust the trim piece dimensions.

Our oak edge trim came in four 8' lengths, plus one 6' length. From each 8' piece we cut two 41"-long side pieces and one 13 3/16"-long cross piece, with just over ½" of waste material. Two 8' lengths are almost enough for one enclosure, if you measure and cut carefully! The trim across the front and rear baffles, and under the line exit, was cut from the single 6' length.

VENEER FINISHING. We'll describe fitting a side panel veneer piece first, assuming that one side of your cabinet is perfect, and there's a goof on the other side caused by a narrow front and rear baffle (*Figs. 2* and *3*).

49. Remove the drivers and return them to their shipping cartons. Remove the unglued side panel of each enclosure, apply glue, and screw it down. Before

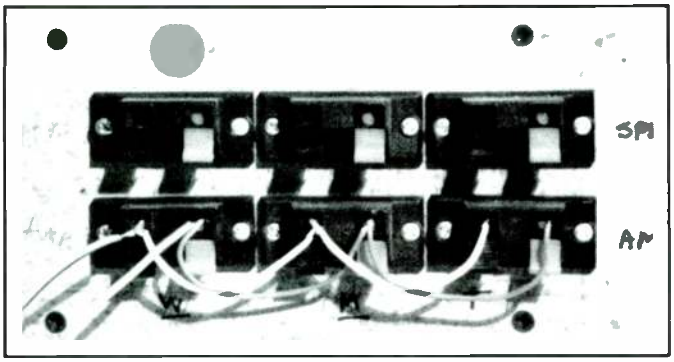

PHOTO 3: Rear view of contest crossover enclosure. Note color-coded marker dots above spring clips.

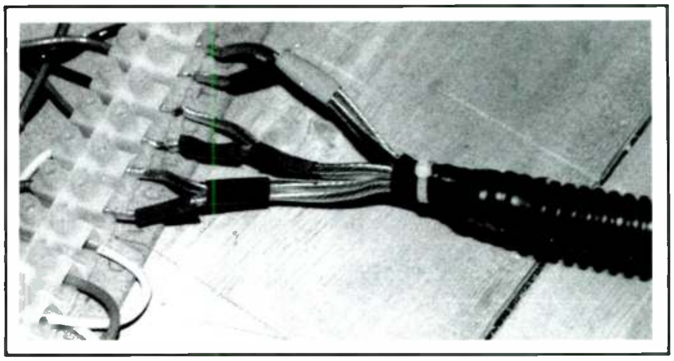

PHOTO 4: Cable loom assembly.

applying the enclosure finish materials, you'll need to decide what to do with the front baffle and rear panel. We sprayed both back and front panels with flat black paint.

50. Lay the enclosure on its side and place a piece of veneered plywood on the accessible side. The plywood should be the same height as the MDF enclosure and wide enough so that, when centered, a uniform ½″ of the MDF will show on either side. Once alignment is perfect, temporarily clamp the plywood. Pad the clamp feet to avoid damaging the veneer.

51. With a drill and a small bit, make 4–6 locating holes through the plywood in various places and into (but not through) the MDF. The holes should be a tight fit for a 4d finish nail. Remove the clamps and the plywood veneer piece. Remember which side of the veneer faces up!

52. Spread a thin layer of latex construction adhesive, then relocate the plywood veneer piece, using the nails to find the exact position. Drive the 4d finish nails with a smooth-faced hammer, but leave the nail heads proud (sticking out a bit) to avoid dimples in the veneer. The nails serve only to locate the plywood and prevent it from shifting, not to draw the veneer down against the glue.

53. Clamp the plywood to the enclosure with bar clamps, distributing the pressure with pieces of smooth-sided scrap between the clamp foot and the work (*Photo 5*). Keep the clamp bars perpendicular to the work, or they will shift the veneer out of alignment.

54. Do not clamp with heavy pressure, and do not be concerned if little or no adhesive is squeezed from the joint. Unlike woodworker's glue, construction adhesive tends to lie in a thickish layer between the pieces, and actually makes a stronger bond that way. Since it remains flexible, it helps to damp the enclosure wall. If some excess glue oozes out, clean it up with a stick before it dries.

55. Repeat the previous steps on the other enclosure, then let the glue dry. Countersink the nails just below the surface with a small nailset and hammer. Then turn the enclosures over and fasten veneer on the other side, as previously described. When a veneered side faces down, protect it with pieces of old carpet or some other padding.

56. Stand the cabinets upright to fasten the top pieces. Drill for a few finish nails, and use C-clamps through the woofer

Continued on page 48

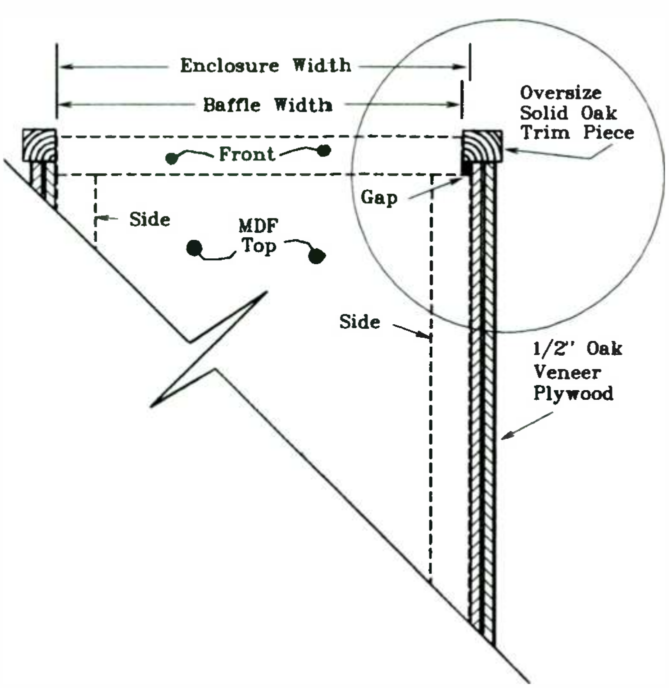

FIGURE 2: Cabinet top view.

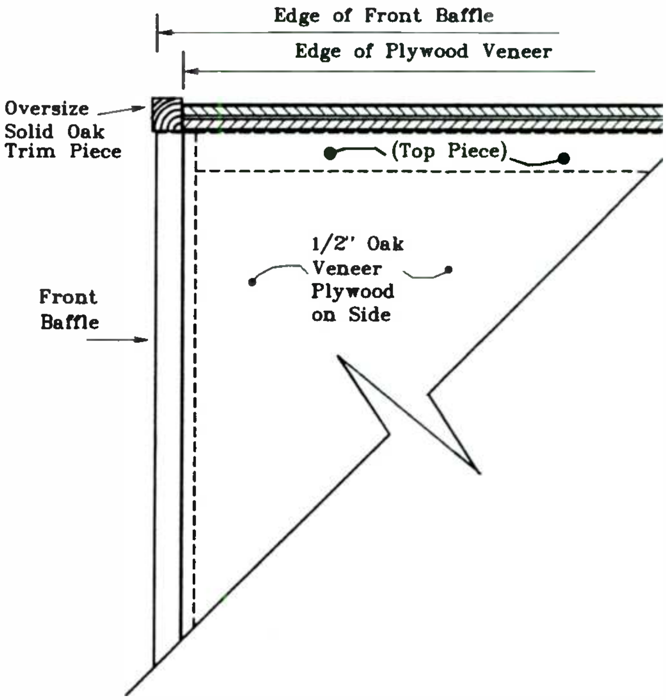

FIGURE 3: Cabinet side view.

Madisound Packers Clearance Sale

QTY	Item	Price
239	Audax DTW100T25FFF, 1″ textile dome with ferrofluid fs1200 Hz, 90dB, 50W, 8 ohm, 4″ metal flange	$13.00
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900	TRW 2.5mfd mylar capacitor, 10% 300V DC, long leads	10 for $2
130	Peerless 8″ poly cone rubber surround woofer #1701, 8 ohm fs 25Hz, Qts .33, Vas 101, 89db, 100W, 5.5mm X-max peak	$27.00
325	Danmar 12″ woofer, paper cone, foam surround, 25W (compound ?)	$9.00
155	Motorola square Piezo horn tweeters	$5.00
85	Carbonneau 8″ shielded magnet paper cone woofer with foam surround, fs 35Hz, Qts .32, Vas 81, 91dB, 4 ohm	$15.00
140	Focal T120K kevlar inverted dome tweeter, fs 680, 100W, 93.5dB	$45.00
120	Solen Perfect Lay 3.0 mH 14awg inductor	$12.00
5,600	6.8 mfd mylar capacitor, 50V, 2¼″ leads	10 for $4
170	Electro-Voice T35A horn tweeter, 104dB, fs 5K, Below Cost	$22.00
65	Peerless 2604 8″ poly cone foam surround 4 ohm woofer fs 31Hz, Qts .28, Vas 96L, 94dB, 150 W	$25.00
145	Philips AD11600 1″ textile dome tweeter, 3¾″ square, 8Ω 90dB	$10.00
50	Dynaudio 30W100 4 or 8 ohm woofers, cast frame,poly, foam	$200.00
800	Audax DW6x11M 8ohm 3/4″ dome tweeter, 6cm x 11cm	$6.00
50	Famous maker (nose)6.5″ woofer, sealed box, fs 69, Qts .55, Vas 10	$7.50
40	Vifa D25TG-67 1″ poly dome twtr, w/truncated faceplate, tinsel lead	$9.00
185	Peerless 1715 12″ CC line woofer, poly cone rubber surround, fs 18, Qts .28, Vas 372L, 5mm X-max, 8 ohm, should mount vertically	$45.00
50	Electro Voice Turbosound 10″ mid, model LS-1001E for horn load	$45.00
400	T.I. 33 mfd electrolytic 100V non-polar capacitor	$0.50
140	Peerless 1826 Wide Angle 4ohm tweeter, fs 870, 94.5dB	$13.00
230	Eminence 10″ T1040 paper cone, cloth surround woofer 40oz magnet, fs 23.8Hz, Qts .33, Vas 239L, 93dB, 100W	$25.00
290	Audax DTW9.8Ti25BaCavFFG 1″ titanium dome tweeter w/Grill, 8ohm, fs 1200, 91dB, 50W, ff cooled	$10.00
24	Black-Dahlia cabinet in black stained oak	$45.00
400	80mfd Chateauroux polypropylene capacitor, 5%, 150V	$15.00

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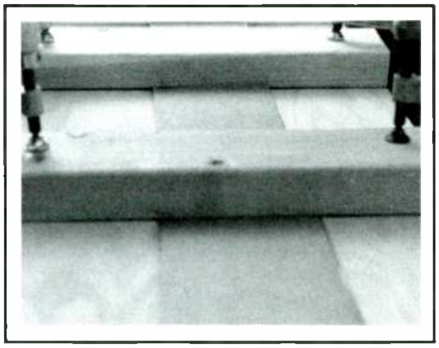

PHOTO 5: Clamping side veneer panel. Cardboard strip under clamping blocks centers pressure.

Continued from page 46

opening and long-bar clamps, which catch the edge of the terminal recess to apply downward pressure to the top. If you don't have clamps, heavy weights will suffice. We've had good results with a half-empty bag (20–25 lbs.) of sand.

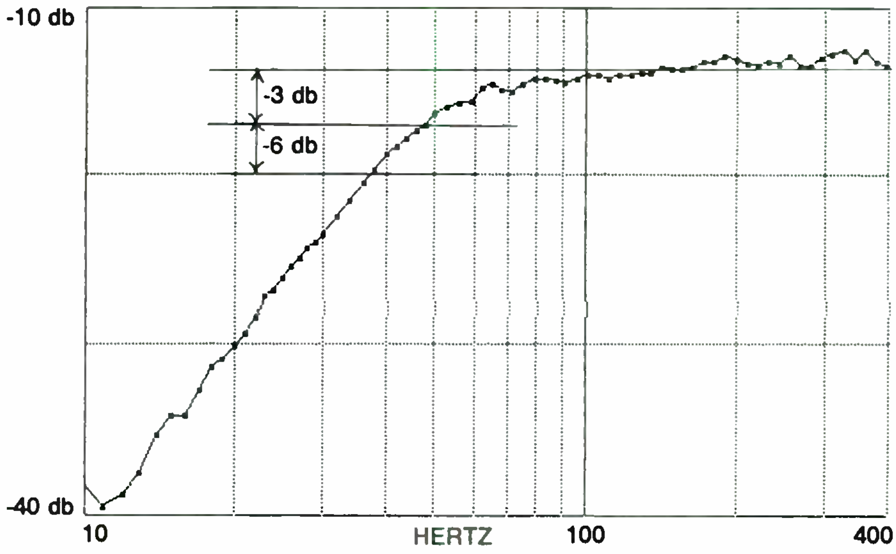

FIGURE 4: Combined output of Brother Jon's woofer taken in the near field.

EDGE TRIM.

57. When the glue is dry, use a sharp chisel or knife to remove any beads that may lie in the apex of the joint between the veneer pieces. A clean 90° angle is necessary to properly apply the edge trim.

58. Cut the long edge pieces to length first (these will be vertical when the cabinet stands upright). They should be exactly the length of the side veneer pieces. If they are a bit longer, the excess should overhang the base of the enclosure where they can later be planed flush. If a piece is short, you must cut another.

59. Place one enclosure on its side on the workbench. With white or yellow carpenter's glue, fasten the trim one piece at a time. Take care that the clamp feet rest on the solid trim and not on the veneer surface. Keep plenty of clean, flat scrap handy for padding the opposing clamp feet, and clean up all wet glue immediately. Do the corresponding piece of side trim on the other enclosure.

60. After the glue has set (generally about 45–60 minutes for Elmer's), use a very sharp low angle block plane to trim the piece flush with the veneer surface (*Photo 6*). We stop just a hair short of flush and finish with a cabinet scraper (*Photo 7*), because sometimes even a well-sharpened plane blade will tear the veneer. With a straight-edge and your fingertips, check the quality of the joint.

61. Work around the cabinet edges sequentially until all the side trim is glued and planed. Finally, plane flush any excess length of side trim extending under the enclosure.

62. Stand the enclosures upright to apply the four pieces of edge trim, which lie horizontally, around the top (*Photo 8*). The order of application is not critical, but it's best to apply one piece at a time to each enclosure and work around all four edges sequentially, as previously described.

63. Unlike the vertical edge trim pieces, the horizontal pieces require mitered corners. We cut these by hand using a miter saw (*Photo 9*), and with some practice you can cut to the right dimension almost every time. Remember to allow for the set of the saw teeth and leave each piece just a hair long. Use the well-sharpened block plane to take the finest shavings from the beveled edge where needed for final fitting. Cut-and-try is the only way to achieve a nice joint.

64. Planing the horizontal edge trim flush is more difficult due to the miter joints. Which face you do first doesn't matter, but you must plane into the work. This means the plane cannot exit

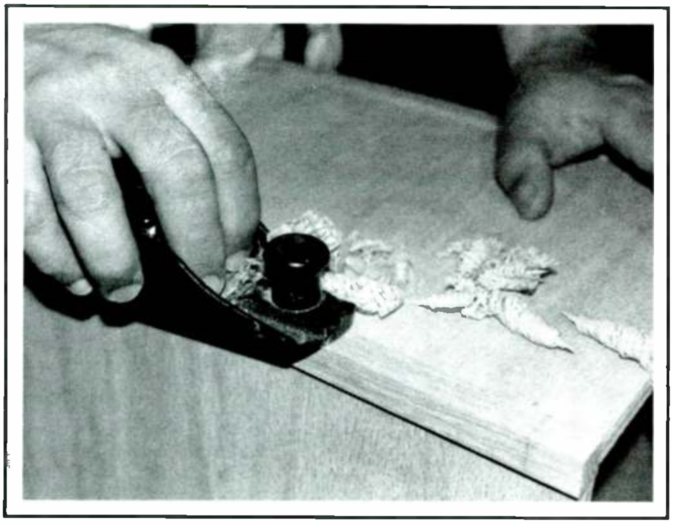

PHOTO 6: Planing a piece of solid oak trim.

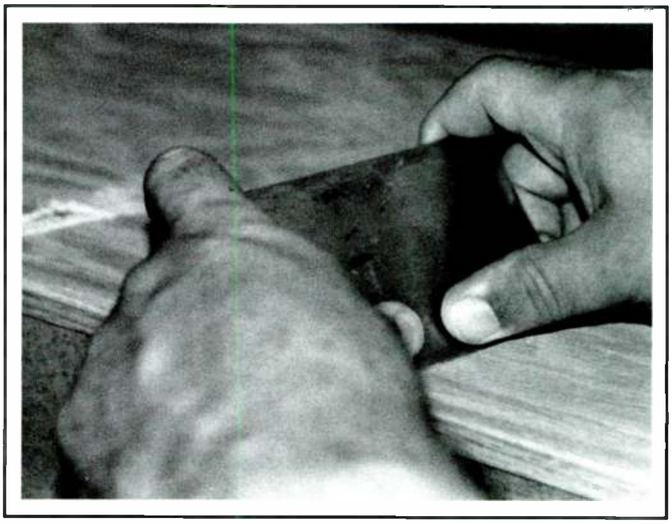

PHOTO 7: Scraping a piece of solid oak trim.

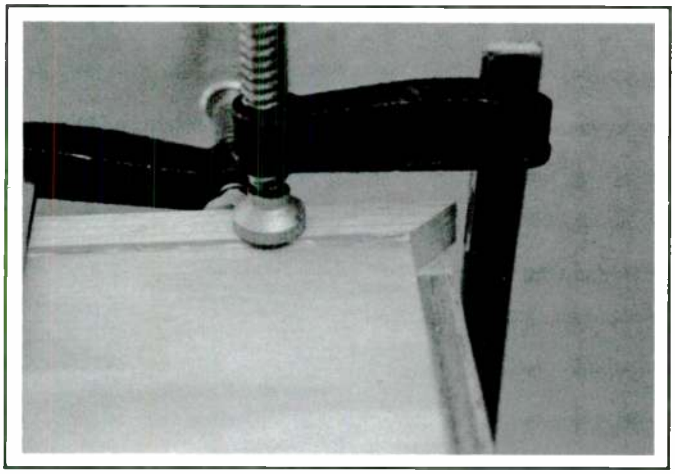

PHOTO 8: Clamping a piece of top trim.

PHOTO 9: Cutting 45° bevels for top trim stock.

the work at the far end of your stroke. Stop one-half to two-thirds of the way through and plane from the other side to meet your cut in the middle. This is awkward, but the plane can be effectively used Japanese-style: pulled rather than pushed. Angle the plane to produce a shearing cut and you will reduce the chances of tearing the oak.

65. Cut a piece of trim to fit tightly on the enclosure's bottom at the line exit (*Photo 10*), then fasten it with carpenter's glue. When dry, plane all its surfaces flush.

66. The 90° edges will be rather sharp at this point, and must be "broken" (made less acute) or some finishes will not adhere well. We planed a chamfer on all edges using a block plane, and then softened the resulting 45° corners with a few strokes of fine garnet paper. If you are proficient with a router, you can use a chamfer bit or a round-over bit instead of a hand plane.

67. Finally, smooth out all the rough spots with a cabinet scraper. This misnamed tool should produce finer shavings than even the block plane can, and works best when it is skewed slightly and tilted forward to produce a shearing cut across the work. Again, work from the outside to the middle and you should end up with an excellent finish.

68. Measure and cut a piece of 2¾" cabinet base molding stock. Clamp without glue and drill for a couple of locator nails, then fasten as described earlier (*Photo 11*). When the glue is dry, set the nail heads below the surface and use a block plane to chamfer the top and front edges of the base. Repeat until both cabinets have base molding on both sides. Plane any overhanging stock flush. Lightly moistening the end grain will make planing much easier.

FINISHING TOUCH. Now take a critical look at your work before proceeding with any kind of finish treatment. If gaps exist between the trim and the veneer, or if the veneer edges were splintered when cut, each and every flaw must be repaired. A mixture of glue and sawdust has been the ancient standby for filling small gaps, but products like Elmer's Professional Carpenter's Wood Filler are inexpensive and easy to use. They dry so quickly that by the time you've worked around the cabinet, the first repair can be sanded and scraped. The end result should look similar to *Photo 12*.

Any unfilled splinters or nail holes, even minutely misaligned pieces, will be magnified by the finish. Every little imperfection will leap out to annoy you, so be patient and use a strong, low angle light (like the late afternoon sun) to inspect your progress. We have found that when people like your system's looks, they also tend to like its sounds. Go over the enclosure several times, and don't let yourself off the hook until you are satisfied that nothing further can be done.

We finished the first pair of Brother Jon systems in natural oak using many coats of hand-rubbed Danish oil. The results left nothing to be desired, but they also left us exhausted. The second pair had some problems with chipped veneer that a clear finish couldn't cover up, so we took filler and sandpaper to the cabinets, and then we took them to a local cabinet shop and had them sprayed with black lacquer.

OF MICE AND MOTHS.
69. Once the cabinets are dry and don't produce fumes, add a mouse guard to the opening of the line exit. Use a piece

TABLE 1

CUTTING LIST

PIECE	SIZE	QTY.	DESCRIPTION
Side	12″ × 41″	4	½″ oak-veneer plywood
Top	8″ × 12″	2	½″ oak-veneer plywood
Edge Trim	½″ × ½″	38	lf solid oak
Base Trim	2¾″ × ½″	4	lf solid oak

Note: Measure the depth of the cabinet, subtract 1″, and use that dimension for your cabinet in place of the 12″ dimension shown above for side and top pieces. You'll need to do this if, for example, you've used a 1″ piece of MDF instead of a ¾″ piece for the front baffle.

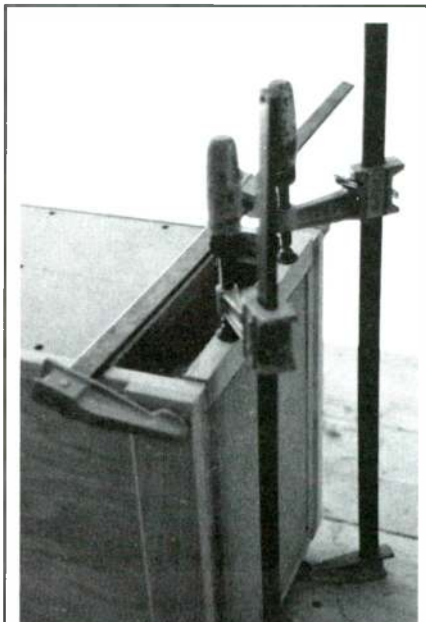

PHOTO 10: Gluing down trim piece at line exit.

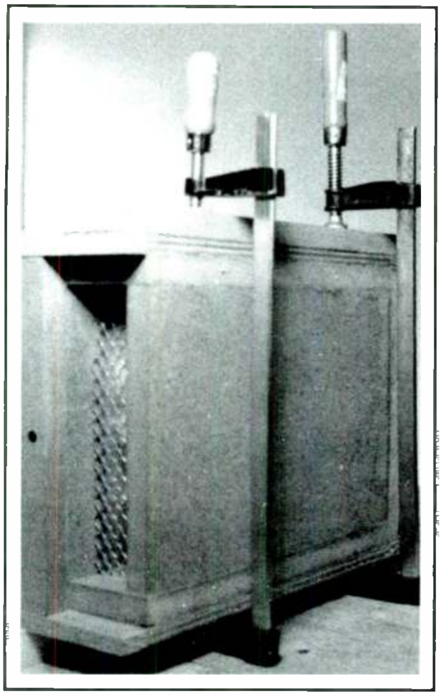

PHOTO 11: Clamping base molding to enclosure side. Note aluminum barrier in recess of line exit.

of slightly oversized heavyweight aluminum gutter guard. Flex and slide it into the opening (*Photo 11*). It should spring into place and hold tightly. If it bends, you've got the lightweight variety. Our guards remained on duty through a rough coast-to-coast trip, so we're confident they will make rodents seek lodging elsewhere.

70. Cut a piece of open-cell foam to friction-fit into the line opening flush with the cabinet trim. Radio Shack's ubiquitous speaker grille foam does the trick here. We reversed it to create a flat surface. This will keep moths and other insects out—a help if you used wool as your stuffing material.

71. The front baffle may need further attention. The first pair of Brother Jon systems received black automobile rear-deck carpet glued down with contact cement (*Photo 13*). This worked well, and some thought it had a beneficial effect on the tweeter output. The second pair's front baffles were covered with Orca Design's heavy vinyl Black Hole pad. This has a nice leather-like appearance and a peel-and-stick rear layer which makes it easy to apply (we used a veneer roller). A third pair looked just fine under black lacquer, so we left it that way. It's your choice here.

72. Lay the material out full-length on the front baffle and glue it down. It will now cover the speaker frame recesses and mounting holes. With a utility knife fitted with a fresh blade, carefully cut around the outline of the speaker frame recesses.

73. The pieces you cut out should now fit the driver recesses exactly, so you can glue the material down and use it as gaskets for your drivers. Then use the utility knife to cut around the circular openings through the baffle, and this part of the job is done.

PAINLESS FRAMES.

74. You can quickly make large grille cloth frames by using window screen kits available in most hardware stores and home centers. The kits we used are from Macklanburg-Duncan (dba MD) in Oklahoma City. The kits produce an attractive, dark, lightweight aluminum frame, with slightly rounded edges and corners. Instructions for snapping the pieces together are included and are easy to follow. All you need is a hacksaw and a steady hand.

75. The outside dimension of the frame width is the width of the enclosure minus 1″. The outside length dimension is taken from the top of the enclosure to the upper edge of the line exit minus ½″. The outside dimensions of the grille frame work out to be just a hair less than

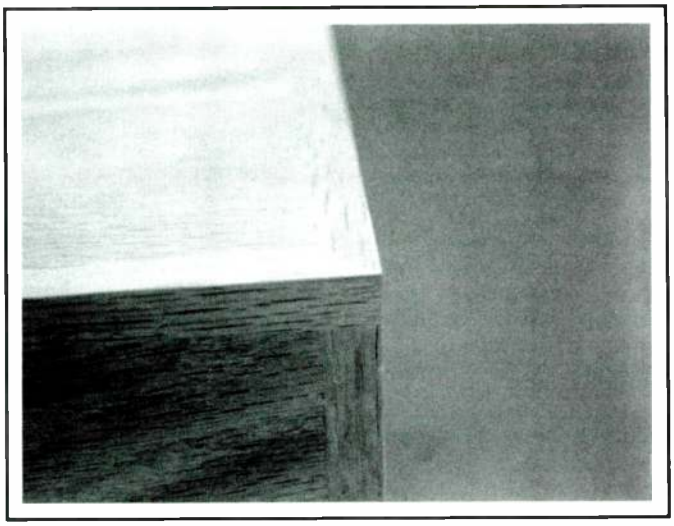

PHOTO 12: Upper corner of unfinished cabinet showing butt joint of vertical trim against mitered joint of top trim.

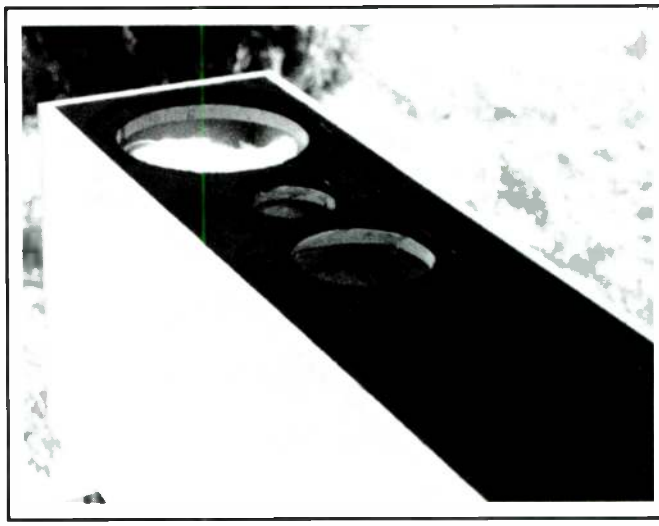

PHOTO 13: Automobile rear deck carpet on front baffle of original Brother Jon.

the inside dimensions of the enclosure's edge trim.

76. When you cut the actual pieces, subtract an additional 1½″ to account for the dimensions of the corner pieces. Cutting aluminum is best done using a fine-tooth hacksaw blade with the work piece against a brace or in a miter box.

77. Since the Brother Jon grille frames are over 3′ in length, a center brace is recommended to prevent inward bowing of the side pieces. The location of the center brace is not critical, but it should be at least 2″ below the lowest driver.

78. If you are going to mount the grille frame with ball-and-socket hardware, now is the time to drill the holes (*Photo 14*). The hardware must be small enough to fit into the hollow center of the aluminum frame, so check carefully before you drill. We suggest using one drilled-out frame as the master for drilling the second frame and the centering holes in both enclosures. This allows the grilles to be interchanged.

79. There isn't much free room above

Continued on page 54

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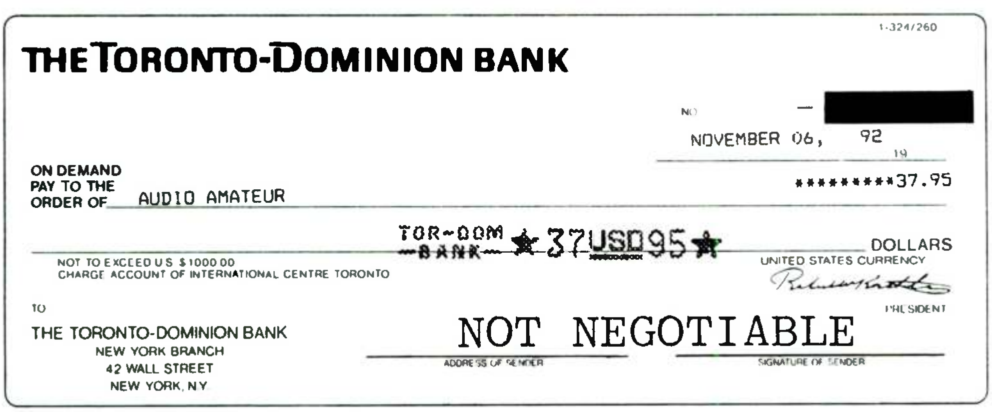

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Continued from page 52

the woofer flange to mount the grille hardware, so the holes must be drilled near the edge and through the horizontal tongue of both the upper and lower corner pieces of the frame. Drill a third pair somewhere in the middle of the long side pieces for a total of six holes/frame. Before drilling, be sure the holes don't lie above any of the screws holding the front baffle in place. Don't drill any holes in the center brace, since it is held in place by friction.

80. Place the enclosures on their backs, and position the empty grille frame. Using a scratch awl or a nail guided by the mounting holes in the grille frame, mark the places on the front baffle to be drilled for the frame mounting hardware. Drill the mounting holes, taking care not to drill all the way through the baffle.

81. You digress from MD's printed instructions at the point where you use stretch fabric for speaker grilles instead of screening material. Also, the grille fabric is stretched around the outside of the frames, and the spline groove faces inward toward the baffle.

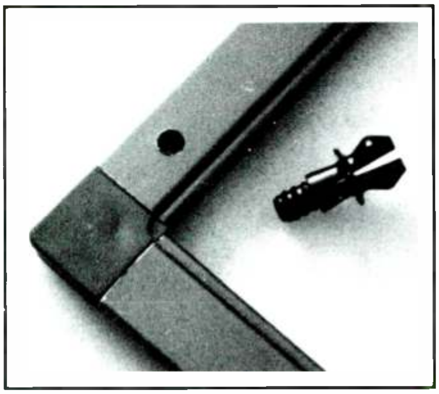

PHOTO 14: Aluminum pieces of grille cloth frame showing plastic corner piece and location of hole for stand-off.

82. Cut a slightly oversized piece of grille cloth. We started on a long end and fastened the cloth with a length of spline and a spline roller (available where you got the screen kits). It may take several tries to learn how much to stretch the cloth, but even if you botch the job completely, you can remove the spline and start over as often as necessary.

83. The worst part is getting MD's label off the aluminum stock, unless you want bar codes on your project forever. Even when the labels peel off, large amounts of sticky adhesive can be left behind. Mineral spirits or contact cement solvent will clean this off.

84. When you are satisfied with the grille, trim the excess fabric with a sharp utility knife. For ball-and-socket hardware, you must make a small hole in the

Continued on page 69

SOURCES

Macklanburg-Duncan
Oklahoma City, OK 73118
(800) 654-8454
"Window System II"

A&S Speakers
3170 23rd St.
San Francisco, CA 94110
(415) 641-4573
Drivers, crossovers, and wool

A Tale of Two Crossovers

All things done in haste end badly, or so the old saying goes. This was nearly the case for us with our competition version of the Brother Jon. Having swapped out the original woofer and tweeter for last-minute replacements, we found ourselves in a quandary about the crossover. The old woofer had a 10Ω impedance, the new woofer had a 6Ω impedance, and we had only a few weeks left to meet the shipping deadine for the contest. We needed a new crossover, and we needed it in a hurry.

The Focal F444 seemed to fit the bill, so we substituted it for the original F433 at the last minute. Some of our component values are different than the original. We reworked the circuitry to give each filter a separate ground, and we added an L-pad to the tweeter circuit. We wanted to make further changes with a view toward lowering the parts count, but couldn't spare the time for it. The system was up and running for exactly half an hour before we disassembled it for shipping. While there were good reasons behind this unseemly haste (Part I, *SB* 4/92, p. 10), we wouldn't do it that way again.

The system as shipped sounded very new to us—tight and a bit strained. We rationalized that the drivers needed to be exercised. Our only way of testing the system was with our ears and some rudimentary near field sine wave sweeps for the woofer. *Stereophile*'s sophisticated measurements astonished us (*Stereophile*, Vol. 15, No. 3, pp. 146–151). Most of the problems mentioned by both the A&S judges and the *Stereophile* reviewer pointed toward problems with the crossover, particularly in the midrange.

TABLE A

CROSSOVER COMPONENT VALUES

Element	Contest (F444 mod)	F433
R1	1.2 Ω	2.4 Ω
R2	2 Ω	3.9 Ω
R3	23.5 Ω	omit
R4	1.2 Ω	1.2 Ω
R5	4 Ω	1.2 Ω
R6	omit	35 Ω
L1	0.16 mH	0.16 mH
L2	0.35 mH	0.5 mH
L3	1.25 mH	1.6 mH
L4	1 mH	2 mH
L5	0.7 mH	0.5 mH
L6	1.5 mH	3 mH
C1	3 μF	5.1 μF
C2	3 μF	3.9 μF
C3	33 μF	22 μF
C4	0.66 μF	0.47 μF
C5	10 μF	10 μF
C6	33 μF	32 μF
C7	74 μF	100 μF
C8	100 μF	50 μF

When the speakers were returned to us, they had been damaged in shipping. Several months passed while the insurance claims were settled and the speakers repaired. We then made A-B comparisons between the modified contest F444 networks and the modified F433 design we'd originally used. The main difference between the two designs is that the F433 has lower crossover points between drivers. The Brother Jon was much happier with the F433, which shows the dangers of swapping crossovers between systems. For example, both networks have notch filters in their low-pass sections, but the resonances they were designed to trap don't exist in the Brother Jon.

Although we prefer and recommend the F433, the speakers that won the contest used the F444. We decided to let you take your pick. *Figure 1* shows the crossover schematic, which is nearly identical for both designs. *Table 1* gives the values for all resistors, capacitors, and inductors. Note the variation in values, the omission or inclusion of a few resistors between designs, and the reversed tweeter phase for the F444.

Last Minute: Focal has added the 8V416-J to their 8V polyglass woofer series. The 8V416-J is electrically and mechanically identical to the 8V416 except for a double back plate which leaves more room behind the voice coil. We've tried both models and either performs well in our system, but the J allows greater cone excursion for better low bass performance.

Wayland's Wood World

HAND TOOLS FOR SPEAKER BUILDING

By Bob Wayland

My speaker construction reflects the pride I feel for my accomplishments in audio reproduction. As I developed my skills, I found that new and better tools are not enough. However, building the enclosures well is essential, whether you use simple hand or sophisticated power tools. True, the better the tool, the easier the job, but cost determines priorities. In this series, I'll provide an overview of tools useful for speaker building so you may choose the right combination for your needs. Part I will focus on general safety considerations and hand tools.

Tools define our level of craftsmanship. We all use hand tools such as chisels, scrapers and planes. The hand-tool woodworker usually cuts panels with circular saws and uses a router to make tongue and groove joints. The advanced woodworker tends to use stationary power tools such as table saws, planers and jointers. Both approaches have their advantages and disadvantages, with cost often the dominant consideration.

With patience, practice and devotion, either approach can produce superior speaker enclosures. Beware: the field of woodworking tools tends to jump from one fad to another. Remember, your grandfather could buy well-built furniture made with little more than hand tools.

Safety

The first workshop consideration should be safety. Your sight, hearing, respiratory system, and your hands, in particular, are in constant danger.

Lighting: Simple fluorescent lights are inexpensive insurance. You will also find good use for a focusing flashlight.

Eye protection: Glasses may reduce the danger of flying objects, especially safety glasses with polycarbonate lenses and clip-on side shields. For those who don't need glasses, the nuisance of goggles is a small price to pay. One overlooked aspect of eye protection is the irritation caused by dust, especially from some of the more exotic woods.

Hearing protection: I have a constant ringing in my ears caused by improper hearing protection. My shop now looks like a museum of hearing protection devices. The moldable insertion plugs work best, but are messy and often uncomfortable. The ear-muff type may cause discomfort for those who wear glasses, but are very effective if worn snugly. Spring-clamped ear plugs are sometimes a convenient solution. The ones that work best for me are available for about $10. A good place to shop for hearing protectors is your local gun store.

Breathing: "Brown lung" disease is causing quite a stir in the woodworking industry, and with good reason. A good dust control system can help protect you. If you can't afford the cost or space for one, you could use a respirator. Filtering out dust alone is not enough; filter mist and vapors from sprays, paints, lacquers, varnishes and enamels. Don't depend on cheap throw-away masks; if you are going to be using petroleum-based finishes, an industrial-rated respirator such as #50R04.01 from Garrett Wade (about $50) is useful.

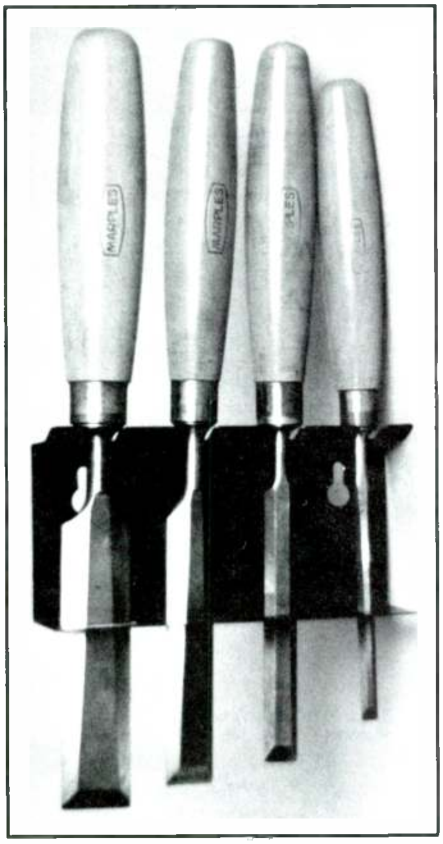

PHOTO 1: A set of Marples finish chisels in a wall rack.

Ventilation: This can be a real problem, especially in a garage. If you don't have an exhaust fan, you could get a large fan and set it in the doorway. A good shop vacuum is also helpful.

Tool placement: Have you ever lost a delicate set-up trying to reach for a screwdriver that is rolling away? Be sure you never have to make an uncomfortable movement while using any tool.

Clothing: You should wear gloves only when moving rough lumber. Never attempt a woodworking operation wearing gloves, since most of your control comes from the feel of the wood. Also, avoid wearing loose clothing, which can get caught in machinery and pull you into harm's way.

Selection

The care with which you select and use your hand tools is a key to producing a quality enclosure. Power tools allow you to quickly make a piece, but for the final fitting and finishing you will need hand tools. Anyone can buy tools that are exquisite in design, performance and price; the real test is to buy superior tools at a good price.

In addition to catalogs, many other sources can save you money and time. Ads in magazines such as *American Woodworker* or *Fine Woodworking* are valuable. If you are lucky enough to live near a good tool supply house, a periodic visit can provide insight through a first-hand examination.

Another bit of advice: most manufacturers will not fine-tune a tool before shipping. They expect users to fine-tune to their own specifications. A good general book on the finish manufacturing of most hand tools is Michael Dunbar's *Restoring, Tuning and Using Classic Woodworking Tools* (Taunton Press, 63 South Main St., PO Box 5506, Newtown, CT 06470, (203) 426-8171).

The Tools

Planes: A plane is a versatile tool which can rapidly rough out stock, and also smooth, square up and quickly make joints. Two general classes—bench and specialty—are the most useful.

A good beginning selection of bench planes includes a jack plane, for general work, and a block plane, for one-handed clean-up and trimming work. A Stanley or Record jack plane will cost about $75, and a usable block plane about $40. You can buy blades to make your own planes for about $20-25. Consult the pamphlet "How to Make a Plane" (available from Garrett Wade for $5). Also useful is John Sainsbury's *Planecraft: A Woodworker's Handbook* (Sterling Publishing Co., 387 Park Ave. South, New York, NY 10016, (212) 532-7160).

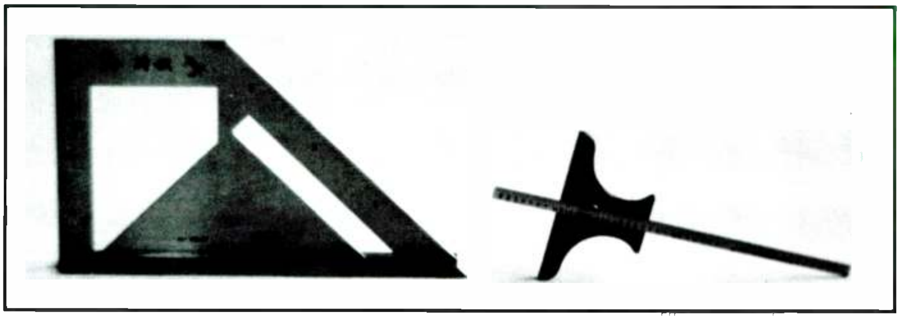

PHOTO 2: The Japanese try square and the adjustable depth gauge.

Hand Saws: A hand saw's utility depends upon how you plan to cut up panels or make finishing cuts. Keep in mind comfort, balance, tooth pattern and ease of sharpening teeth. For solid woods, you will probably need a rip saw for cutting with the grain, and a crosscut saw for cutting cross-grain. For cutting plywood and medium-density fiberboard (MDF), a crosscut saw is your best choice. If you plan to make your speakers from plywood or MDF using a circular or table saw, you can get by without a hand saw by overcutting and using a plane to clean up.

Eastern and Western hand saws have marked differences. Japanese saws, for example, cut on the pull stroke, while American types cut on the push stroke. Japanese saw blades are thinner and produce finer cuts, as cuts are made under tension. The Japanese saw is lighter, giving you greater control and accuracy.

Of Japanese saws, the Ryoba is the most commonly used, with cross-cut teeth on one side and rip teeth on the other. The popular Dozuki has a single-sided cutting edge; the other edge is a rigid spline. A good buy is the Dozuki Noko Giri Razorsaw (about $40 from The Japanese Woodworker), which has a blade thickness of only 0.012" and 26 teeth/inch for smooth, precise cuts. Consult Toshio Odate's *Japanese Woodworking Tools* (Taunton Press) for a comprehensive examination of other Japanese delights.

Western backsaws (tenon, dovetail, and the like) are great for clean-up but rely upon a heavy stiffing bar on the blade's top to carry the cutting. Should you need to cut curved patterns, consider a bow saw. You can buy a kit and make your own for less than $20.

Chisels: Western chisels are made of a single steel sheet that is hardened and tempered. The cross-sectional shape is usually trapezoidal. A variety of quality chisels are available from Sorby and Marples.

Eastern chisels come in a range of specialized configurations. Japanese chisels are made like a samurai sword, with the cutting edge a harder steel laminated to a softer steel for strength and shock absorption. The harder cutting steel comes in two grades, white and blue; blue is the higher quality. The Oire Nomi are good general-purpose tools.

You can expect to pay $40-75 for a good Japanese ½" chisel. Compared to a $10 Western ½" chisel, it's well worth it. Remember, Japanese chisels are designed for softer woods. If you use them on hardwoods, make small cuts, frequently cleaning away the waste.

Chisels are generally offered in sets with standard groupings of ¼", ½", ¾" and 1". For speaker building, you will seldom need the two larger chisels (note the use of the ½" in my set of finishing chisels, *Photo 1*) and can better spend your money on specialized chisels.

Most people have two sets: one for rough use, and one for finishing work. For removing dried glue and crude material, use a cheap ½" chisel from your local hardware store. For a good start, buy a ¼" and a ½" chisel for $10-15 each and add to your collection as needed.

Traditional practice suggests using a wooden mallet for Western chisels and a steel hammer for Eastern chisels. Of the wooden mallets, a good choice is the Lignum Vitae, turned while semi-green from one of the densest woods known. Some woodworkers prefer a urethane-headed mallet, which provides a longer impact for smoother cuts. The steel hammer used for Japanese plane adjusting comes with one face flat and the other crowned for fine work. These hammers vary in weight from about 5-13 oz.

All chisels require frequent sharpening, and new ones need extensive working before they are ready to use. Patrick Spielman's *Sharpening Basics* (Sterling Publishing Co.) is a good place to begin.

Scrapers: Scrapers are pieces of thin-tempered, high-quality steel, usually rectangular, used to clear and surface wood. *Tage Frid Teaches Woodworking—Joinery* (Taunton Press) describes their sharpening, preparation, and use.

Measuring and Marking Tools: The key to the marking process is the production of a fine line, whether a pencil mark or cut, that is easily seen. If the marking is critical, you need a good marking knife (available for around $10). Otherwise, I use a mechanical pencil with 0.5mm lead. The Western version of the marking knife has a standard blade on one end for cross-grain marking and a square ground blade for marking with the grain on the other end. The awl is another useful marking tool which does not have as fine a line as the knife.

The Japanese marking knife, Shirobiki, is the traditional laminated steel type. One side is beveled to allow the cutting edge to ride flush against the measuring edge. It even comes in a left-handed version.

A lasting annoyance is an off-square panel caused by an inaccurately laid out cutting pattern. You can use two basic measuring tools to rectify this: try (miter) squares and straightedge rules. Bridge City squares and rules are guaranteed to provide accuracy of better than twice the industry standard.

For $10-15, you can get good Japanese combination squares (45° and 90°) machined from solid stainless steel which have wide bases that can be hooked against the stock edge or placed upright (*Photo 2*, left). You also need a good straightedge rule, since most accurate work must be done to 1/64" or better. Also

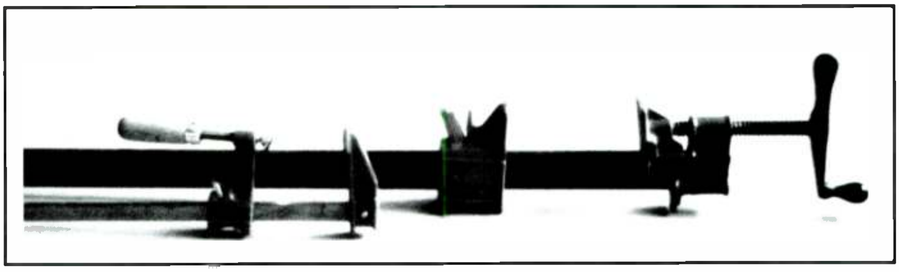

PHOTO 3: The heavy-duty Series 72 Jorgensen I-beam (back) and the lighter-duty bar clamp (foreground).

TABLE 1			
ESSENTIAL-HIGH-END TOOLS			
ITEM	**ESSENTIAL**	**INTERMED.**	**HIGH-END**
ear plugs	$10	$20	$20
respirator			50
dust control	10	80	200
block plane	20	40	80
jack plane		75	120
cross cut saw		25	
Dozuki			40
chisels	20	40	120
mallet	10	20	25
sharpening stones	40	60	100
scraper			8–40
24" rule	30	30	30
depth gauge		15	15
try square	15	40	100
clamps	20	60	200
TOTAL	$175	$505	$1,140

valuable is a depth and angle gauge with a lockable sliding head marked for 30°, 45° and 90° (*Photo 2*, right).

Clamps complete our survey of hand tools. We all recognize the need for deep-tapered screws set in a strong base for C clamps. Bar clamps, such as those made by Record and Jorgensen (*Photo 3*), are also useful. The lighter versions are steel bars $\frac{5}{16}$" × 1$\frac{3}{8}$" with fixed heads at one end, and a moving jaw that can clamp up to 12", 24", 36" and 48". The throat depth varies from about 2½" to 5". There are many cheap versions of these clamps at your local hardware store—don't even think about buying them.

For heavy-duty work, use the Record T-bar and Jorgensen I-bar clamps. The Record T-bar has an optional 4' lengthening bar. You can use hand-screw clamps to build satellite enclosures, but they are expensive. If you plan to make a large number of panels from solid stock, you can find specialty clamping systems.

Tool Kits

By now I'm sure you're thinking, "But what do I need?" I can only suggest what I would buy for different approaches. *Table 1* spans the range of essential to high-end items.

Nothing about this list is sacred; we all have different ideas and goals. Next time, we'll take a look at the power tools that can help enhance your speaker construction efforts.

MAIL ORDER SOURCE LIST

Advanced Machinery Imports, Ltd.
PO Box 312
New Castle, DE 19720
(302) 322-2226
Specialty clamping systems

Garrett Wade
161 Ave. of the Americas
New York, NY 10013-1299
(212) 807-1155
(800) 221-2942

Highland Hardware
1045 N. Highland Ave. NE
Atlanta, GA 30306
(800) 241-6748

The Japan Woodworker
1731 Clement Ave.
Alameda, CA 94501

Trend-lines
375 Beacham St.
Chelsea, MA 02150
(800) 767-9999

The Woodworkers' Store
21801 Industrial Blvd.
Rogers, MN 55374-9514
(612) 428-3200

Woodcraft
210 Wood County Industrial Park
PO Box 1686
Parkersburg, WV 26102-1686
(800) 225-1153

Woodworker's Supply
5604 Alameda Place NE
Albuquerque, NM 87113-2100
(800) 645-9292

Ask SB

POWER RATING

By Dick Pierce

Danny Halamish writes: "Can you explain how speaker power ratings are calculated? I see many amplifiers and even portable radio/cassette players rated at 100W. My modest amplifier is rated at 15+15W. When I play it at volume 3, it sounds significantly louder than some 50W amplifiers at full volume, and even louder than a 100W amplifier I have heard. Would manufacturers (including Sony and Kenwood, among others) be misleading us? I understand that PMPO rating is about twice as high as RMS, but my 30W amplifier easily beats 100W, and my speakers are only rated at 20W. How can this be?"

The whole issue of power rating and power handling is very confusing. Some manufacturers exploit this confusion to set forth ridiculous ratings.

Amplifier Power Ratings

First, let's look at amplifiers. In the mid-1970s, the Federal Trade Commission established regulations which defined amplifier "power." They stated that the amplifier must undergo a break-in/warm-up period in which it is run for at least one hour at one-third its rated power. The amplifier must then produce its rated power, at or below its rated distortion, over its rated bandwidth for any length of time. If it passes this test, the rating is considered accurate.

Advertising any other power rating is illegal. If a manufacturer follows the rules (and fewer do these days, especially with so-called "rack" systems), you'll see specifications like "minimum 45+45W RMS at less than 0.1% total harmonic distortion from 35Hz-20kHz."

The FTC testing methods have several problems. For example, the one-third power warm-up level was arbitrarily selected and disregards two important considerations. First, in "normal" use—playing average music at realistic levels with average loudspeakers—most systems put out only a few watts, so a better choice might have been a warm-up of 5W. Second, one-third of rated power nears the point at which output devices are working the hardest and dissipating the most heat.

Makers Moaning

This test provides a set of difficult-to-meet requirements, but is also a conservative worst-case scenario. While passing the test is no indication of perfection, it does provide a minimum set of requirements.

The FTC provided manufacturers a year in which to comment before the regulations became official, but not one bothered to respond. Once the regulations were in effect, a great outcry ensued. Half of the amplifiers and receivers on the market had to be down-rated, in most cases because of the extreme thermal stress the one-third power rule caused.

Silly Rules

Despite much moaning from manufacturers, the new regulations are a vast improvement over those that existed before. Most manufacturers rated their amplifiers in RMS power over a specified bandwidth (usually 20Hz-20kHz minimum), which was a dependable specification of what the amplifier could do in terms of producing real power that translated directly into sound-pressure level.

Of the half dozen ways to rate amplifier power, however, most are deceptive. (Consider the EIA specification referring to "peak power.") The worst concerned the inhibit flip-flop (IHF) peak power output, which was calculated by using the power supply total potential voltage swing only under optimum conditions, and presumed no losses in the amplifier output stages. The resulting figures were often six or eight times greater than what the amplifier could realistically produce. For example, the Lafayette LR-1500 receiver was rated at around 200W, yet the rear panel stated that it consumed only 175W of AC power. If that were true, why were we concerned with controlled fusion power?

The FTC also instituted a silly rule stating that the amplifier model number cannot reflect the power rating. This led to the Yamaha CR400 receiver, which was rated at 20+20W, having its spec changed to 21+21W.

Loudspeaker Power Ratings

This issue is far more complicated. Official standards have been established for rating the power-handling capacity of speakers. Most of them state that the system is first measured and characterized, then subjected over a long period to playing a signal that mimics some of the music's characteristics. Often specified as white noise, this is shaped for a particular amplitude distribution, then filtered to approximate the spectral content of typical music. Usually, this is done with a filter roll-off at about 6dB/octave below 150Hz, and again at 6dB/octave above 200Hz. Different standards specify different filter characteristics, but the intent is essentially the same: loudspeaker level is adjusted so the speaker is driven at its rated power.

Tweeter Heater

After this warm-up period, the speaker is allowed a few minutes to return to room temperature, after which it must pass the initial performance test. This particular test deals with only one aspect of loudspeaker power ratings—long-term thermal stress—and neglects short-term stress and mechanical limits.

As you might guess from the test signal's spectral content, not much of the total power is directed toward the spectrum's high-frequency region, which is gentle on tweeters. Generally, tweeters have very small, delicate (mechanically and thermally) voice coils, often wound from wire that is one-tenth the diameter of wire in a woofer voice coil. Their ability to absorb heat without a temperature rise is limited compared to woofers. Typically, an 8″ woofer would be able to withstand 50 or 60W of continuous broadband signal without any significant damage. A tweeter could easily be fired with a couple of watts of the same signal.

Most musical signals are relatively devoid of large quantities of high-frequency information, which saves tweeters from instantaneous self-destruction. Keep in mind, however, that high-frequency information is often associated with transient signals. These signals, either intentional or accidental, often blow tweeters away.

Jumps and Collisions

Mechanical power limits are most often associated with low-frequency signals. Not only is the musical spectrum weighted toward lower frequencies but, in general, the amount of motion a cone undergoes varies as the inverse square of the frequency. If a cone must move $\frac{1}{1000}$" at 1kHz to produce a given sound pressure level, it must move $\frac{1}{250}$" at 500Hz (one-half the frequency, four times the excursion), or about $\frac{1}{10}$" at 100Hz (one-tenth the frequency, 100 times the excursion). By the time we reach 25Hz, we are asking our hypothetical cone to move over 1½"!

We made some simplifying assumptions for our example which don't occur in real life. The sound pressure we're talking about is very loud, and, as not much real content exists at high frequencies, there is also reduced content at low frequencies as well. We are thus spared trying to make cones move this much.

Two mechanical limits exist for a loudspeaker. The first is determined by the driver's ability to reproduce a signal with minimal distortion (in woofers, this is referred to as X_{MAX}, the maximum linear excursion). The second limit is the point at which mechanical damage occurs, which is caused by components being stressed beyond their capabilities. Damage also results from the cone moving so far that the voice coil collides with the rear part of the magnet structure, or jumps out of the gap completely and becomes misaligned, colliding with the pole piece or the magnet's front plate.

Rack and Mall Fictions

Combinations of several failure modes are possible. For example, extended periods of high power may heat the woofer voice coil enough so that adhesives soften and the voice coil wire loosens. Also, the plastic cone may soften slightly and misalign the voice coil, causing rubbing.

Usually, short-term, high-power, high-frequency-associated thermal stress causes tweeter failure, while short-term, high-power, low-frequency mechanical stress causes woofer failure. Of the hundreds of failed drivers I have inspected, not one tweeter showed signs of mechanical stress; only a dozen woofers have shown stress, primarily thermal.

The various recommended power-rating standards do not adequately address the issues of realistic power handling. Unfortunately, most power ratings used by manufacturers mean nothing. If you see a spec like "Rated for use with amplifiers up to 100W/channel playing undistorted music program material," you can assume the manufacturer is trying to provide realistic guidelines. On the other hand, the power ratings you see on speakers sold with rack systems (or by college students out of the backs of vans in mall parking lots) are fictitious.

Technology Watch

THE SCHROEDER DIFFUSOR

By Peter Muxlow

In average listening rooms, the boundaries are relatively close to the listener and reflect sound waves. If the level of this reflected sound is too high, or if it arrives too close to the direct sound (the loudspeaker sound), it causes interference and alters what the listener hears.

One way to reduce this coloration is to modify the room's surfaces and diffuse the sound. *Figure 1* shows three sound peaks: a narrow peak of original sound; a second delayed peak which is the reflection from a hard wall; and a broad peak of decaying reflections from a diffusor. This third peak has characteristics of an ideal diffusor: with a lower peak level and a later arrival time, the reflections are spread out over a longer period.

Figure 2 displays the spatial or polar response of a hard wall and a diffusor. The wall reflects the sound over a narrow angle, whereas the diffusor scatters the sound over a wide angle. Until recently, good controlled diffusion over a wide frequency range was unattainable.

Quadratic Residue Diffusors

The German acoustician M.R. Schroeder has devised a predictable and efficient method of obtaining controlled diffusion

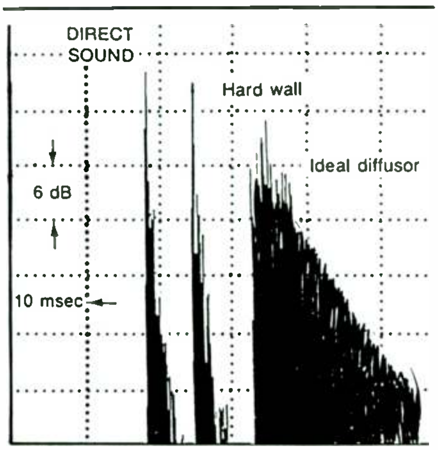

FIGURE 1: (Left to right): A narrow peak of original sound, a second-delayed peak, and a broad peak of decaying reflections from a diffusor.

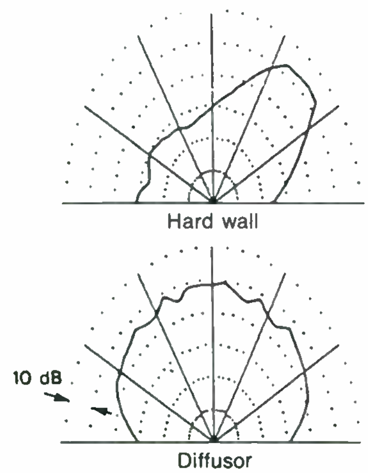

FIGURE 2: Spatial response of a hard wall and a diffusor.

based on reflection phase gratings, which is the acoustical analog of the diffraction grating used to scatter light.[1] The sound is reflected off an array of cavities of equal width but different depths (*Fig. 3*). When a sound pressure wave enters a cavity, it is reflected at the bottom and emerges at the top with a phase change. The varying depths produce path length differences, and therefore phase differences. These reflected waves reinforce or cancel in predetermined directions, depending on the sound's wavelength and the spacing and depth of the cavities.

You can use a mathematical sequence called Quadratic Residues to determine the number of cavities and their depths. When translated to cavity dimensions, the sequence ensures the sound is scattered over wide angles. The Quadratic-Residue diffusor operates predictably over a wide frequency range and produces good diffusion—a breakthrough in controlling room acoustics.

Quadratic Diffusor Design Chart

1. Determine the frequency range for diffusor operation: the ratio of the highest frequency to the lowest frequency.
2. Establish the frequency ratio: a frequency range of four octaves is a 16:1 frequency ratio; a frequency range of three octaves is an 8:1 frequency ratio.
3. Select the nearest prime number on the high side of the frequency ratio.
4. The number of cavities equals a prime number minus one. A frequency range of four octaves has a frequency ratio of 16:1; the chosen prime is 17; the diffusor has 16 cavities. A frequency range of three octaves has a frequency ratio of 8:1; the chosen prime is 11; the diffusor has ten cavities.
5. The cavity depth sequence: the prime number is divided into each of the squares of each cavity number. The prime number is then subtracted from each total, and the remainder is the cavity depth.

For example, a diffusor for four octaves equals frequency ratio 16:1, prime of 17, 16 cavities. The depth of cavity 5: $5^2 = 25$. The prime number 17 goes into 25 once $(1 \times 17 = 17)$, and the remainder $(25 - 17) = 8$. Eight units is the depth of cavity 5.

The depth of cavity 2: $2^2 = 4$. The prime number 17 doesn't go into 4. The

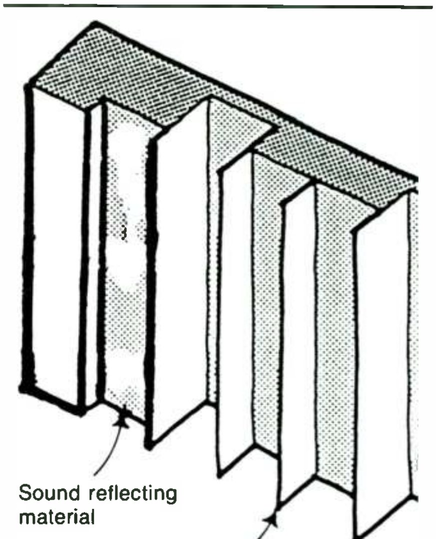

FIGURE 3: Quadratic-residue diffusor.

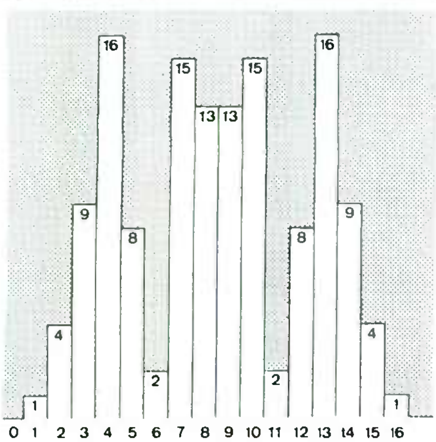

FIGURE 4: Cavity depths.

TABLE 1

CAVITY DEPTHS

CAVITY	NUM.	SEQUENCE cavity depth	DIM. cavity depth (in inches)
0	0	0	0
1	1	1	0.4235
2	4	4	1.69
3	9	9	3.89
4	16	16	6.78
5	25	8	3.39
6	36	2	0.847
7	49	15	6.35
8	64	13	5.50
9	81	13	5.50
10	100	15	6.35
11	121	2	0.847
12	144	8	3.39
13	169	16	6.78
14	196	9	3.81
15	225	4	1.69
16	256	1	0.4235

remainder is 4. Four units is the depth of cavity 2 (*Fig. 4*).

6. The diffusor's physical size is determined by the actual working frequencies.

$$\text{cavity depth (per unit)} = \frac{\text{half wavelength of lowest frequency}}{\text{deepest cavity of sequence}}$$

$$\text{physical cavity depth} = \text{cavity depth} \times \text{number of units}$$

For example, a diffusor for four octaves has a frequency ratio of 16:1, prime of 17, 16 cavities. If the diffusor's lowest frequency is 1kHz (wavelength 6.78"), the deepest cavity (cavity 4) is 16 units. Each unit is 6.78/16 or 0.4235". Cavity depth 5 equals (8 × 0.4235"). Cavity depth 6 equals (2 × 0.4235").

The cavity width equals one-half the wavelength at the required highest frequency. A table for four octaves equals prime 17. The lowest frequency is 1kHz, the highest frequency 1.6kHz. The cavity width equals 0.4237".

REFERENCE

1. Schroeder, M.R., "Towards Better Acoustics for Concert Halls," *Physics Today*, October 1980.

ADDITIONAL REFERENCES

1. D'Antonio, Peter, and John H. Konnert, "The Reflection Phase Grating Diffusor: Design Theory and Application," *JAES*, Vol. 32, No. 4, April 1984, pp. 228-238.

2. Pisha, B.V., and Charles Bilello, "Designing a Home Listening Room," *Audio*, Sept. 1987, pp. 56-63.

PREVIEW

Glass Audio

Issue 2, 1993

- Is the 6DJ8 Suitable for Audio?
- Pro Tube Line Driver
- The Mu Stage
- Custom Tube Electronic Crossover

SB Mailbox

CORRECTION

A misprint appeared in Joe D'Appolito's ARIA 5Ti crossover schematic, published in "Letters," *SB* 6/92 (p. 58). The shunt capacitor (C1) should have a value of $11\mu F$, not $100\mu F$; the wire gauge for L2 is #20AWG. *Figure 1* is the correct schematic.

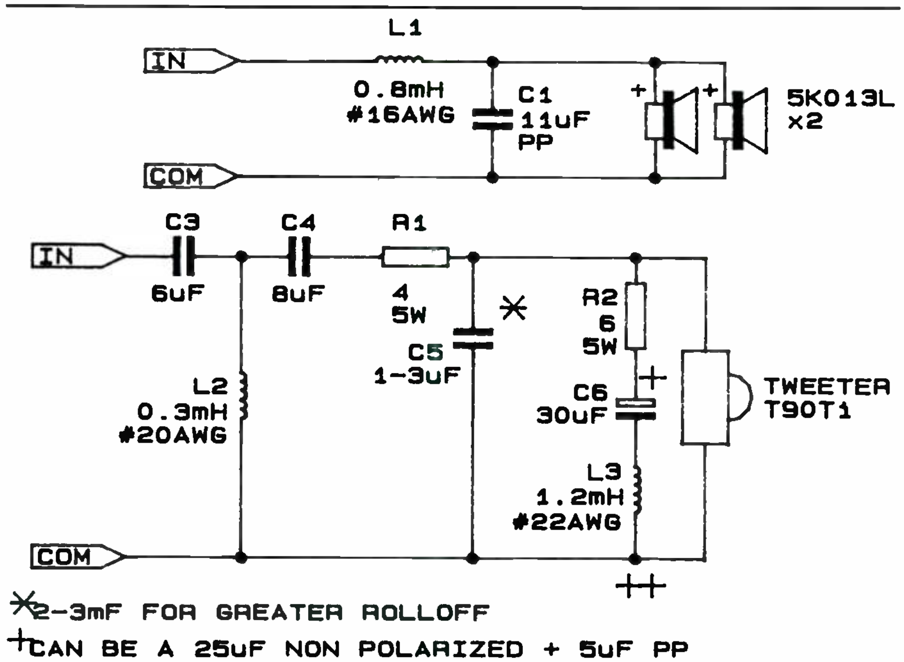

FIGURE 1: ARIA 5Ti crossover.

ARIA 5 MOD

Early last year I completed a pair of ARIA 5 satellites, which I chose after auditioning several commercial units. Colin Whatmough, who manufactures the Whatmough Monitor Range and represents Focal in Australasia, assisted me and was most helpful. We decided to substitute the T90Ti tweeter, for which no data was available at the time.

The results are quite impressive. My setup is almost identical to that suggested by Joe D'Appolito in reply to William Eckle (*SB* 4/92, p. 69) using two Focal 10n515 bi-amped subs in individual 120L ported enclosures. Would Mr. D'Appolito comment on the tweeter switch and whether rebuilding the crossover to ARIA 5Ti specs would yield a worthwhile improvement?

I would like to express my appreciation for your informative publication, which has rekindled my interest in audio after a number of years. Expect my continuing subscription.

R. W. Field
Bonnie Doon 3720, Australia

Contributing Editor Joe D'Appolito replies:

The ARIA 5 has been completely redesigned to use the new Focal T90Ti tweeter and renamed the ARIA 5Ti. In addition to accommodating the new tweeter, the low-pass section has been simplified, incurring much less phase shift and producing a very smooth crossover. The official crossover for this system is shown in *Fig. 1*. The optional capacitor of $1\text{-}3\mu F$ is used for the tweeter's high-frequency rolloff, preferred by some listeners.

STRAIGHT RECORD

I am writing in response to David Delzotto's letter, which appeared in *SB* 6/92 (p. 56). I would like to set the record straight. To begin with, *SB* shows no date for Mr. Delzotto's letter—a major mistake. (*Mr. Delzotto's letter was received at* SB *July 27, 1992. We regret Mr. Zalayet was not invited to comment.—Ed.*) The Focal T90Ti came out about two years ago; I advised Mr. Delzotto two years ago as well. Joe D'Appolito was asked to respond now.

At the time of the "2Ω quick fix," no official and sanctioned Joe D'Appolito crossover existed. However, the new titanium tweeter did and many customers wished to retrofit it to their old ARIA 5s, myself included. So I made this modification on my demo speakers and was happy with the result for that moment—two years ago.

Later on Joe D'Appolito came out with an updated crossover for the ARIA 5Ti, which we have sold from that time to this day. Zalytron has been nicknamed "Orca East" because it is Orca's largest outlet for Focal drivers. So if any company is up-to-date on official or sanctioned crossover designs, you can bet it is Zalytron.

Elliot Zalayet
President, Zalytron Industries Corp.
Mineola, NY 11501

SERIES INDUCTOR

Inspired by Gary Galo's article "Bi-Amping the Sapphire II Sub-1 System" (*SB* 3/92, p. 24), I purchased the Sapphire IITi speakers. I plan to modify a power amp as he suggested to drive the Sapphire IITis in a bi-amped set-up. I already own a subwoofer which requires an external crossover. I'd like to use a Hafler DH-220 power amp for the subwoofer without building an electronic crossover. Can I put an inductor in series with the woofer

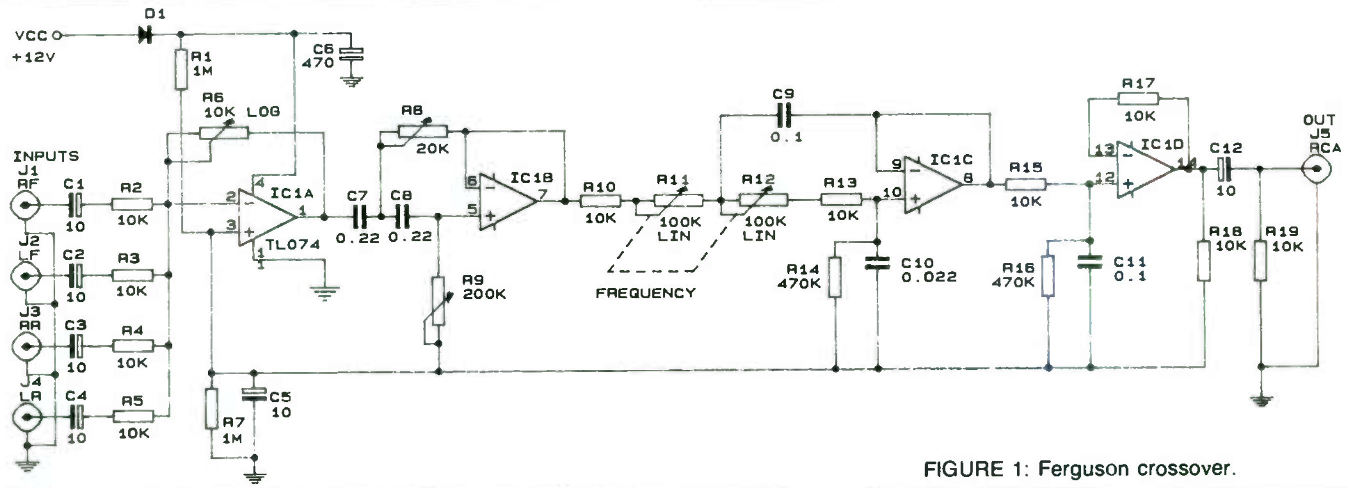

FIGURE 1: Ferguson crossover.

amp's input to provide first-order, low-pass filtering? The DH-220 has an input impedance of 47kΩ.

Arthur M. Wells
Gainesville, FL 32605

Contributing Editor Gary Galo replies:

Mr. Wells poses an interesting question. Unfortunately, the inductor value required would be so large that it would probably be several times as large as the amplifier. The series inductor's value can be found by using the following formula:

$$L = R/6.28 \times F$$

where L is the inductance in henries, R is the amplifier input impedance in ohms, and F is the crossover frequency in hertz. If the subwoofer crossover frequency is 100Hz, then:

$$L = 47{,}000/6.28 \times 100 = 74.8$$

The inductor would have to be nearly 75H! Inductors of only a few millihenries can be several inches in diameter. This inductor would be physically unmanageable, as well as an excellent receiving antenna for hum.

If your subwoofer requires an external crossover, you must build an active crossover network for the low-pass filtering. It will take up far less space than the 75H coil.

MISSED CONNECTION

Dan Ferguson's crossover (*SB*, 6/92, p. 16) should have Pin 11 of IC1A connected to power ground as shown above in the corrected schematic, rather than to virtual ground as printed originally.

B&W RESPONDS

I was interested to read David Moran's "Baffles With Bowers & Wilkins" (*SB* 5/92, p. 74), but I do not understand his obsession with the "Allison effect."

The bass unit is mounted where it will give the best possible vertical dispersion to the system. If the unit were mounted close to the floor, the distance between it and the midrange unit would produce a horrendous dip at 400Hz with any deviation from the exact vertical axis where the crossover was designed. It would also mean mounting the midrange head further back, with the danger of corrupting the amplitude response due to the midrange driver "seeing" the bass enclosure.

As far as the "Allison effect" is concerned, mounting the unit as close as possible to the floor will indeed prevent interference between the direct and first floor reflection, but what of the first side wall and rear wall reflections? We have found this effect to be far less severe than placing the unit closer to the room boundary, which will excessively excite the room eigentones. For this reason many

Continued on page 64

professionals and audiophiles prefer to put the 801 on stands.

I wrote a computer program to optimize loudspeaker placement within three rigid surfaces; it enabled me to produce reasonably smooth curves within the computer. However, in the case of six walls, unknown damping factors and unpredictable diffusion characteristics, the results bore so little resemblance to the computer predictions that I abandoned this path.

Major improvements can be made with careful speaker positioning, but very few rules can be laid down: you just have to keep moving them around and listening. You can't rely upon measurements for the best results. The listening experience is a combination of direct response, early reflections and the reverberant field, all of which are not easy to predict in a room without serious finite element analysis—a subject we are actively pursuing at B&W.

We are also developing a digital room equalization system which will remove some of the worst room characteristics with *no* phase distortion. I am seriously worried if Mr. Moran thinks that a "good ⅓-octave equalizer" is good enough, since this is not our experience or that of the majority of audiophiles.

Mr. Moran also mentioned B&W's bass-EQ component, and showed a complete lack of understanding of the sixth-order alignment. The 800 series has been designed to have perfectly flat response down to cut-off frequencies (in the case of the 801, 19Hz) with a sixth-order Butterworth characteristic. In studio control rooms or well designed domestic rooms, this response is capable of very accurate reproduction at low frequencies. Without the active high-pass alignment filter, the characteristic is a fourth-order Bessel alignment, which we have found to suit a large number of more ordinary domestic situations.

The 801 is one of the most successful loudspeakers ever in its price range, and certainly the most widely used in the monitoring of classical music. What a shame that Mr. Moran is the only one in-step.

Stephen Roe
Development Director
Bowers & Wilkins
England

David Moran replies:

B&W Development Director Stephen Roe misunderstands the Allison effect. But in this he is not alone: most speaker designers and manufacturers I know likewise think it results from "interference between the direct (sound) and first floor reflection," as Mr. Roe puts it. It does not. If it did, it would indeed be less important, less predictable, less inevitable, less worthy of attention and care in designing around it—and less curable.

The Allison effect (or its absence) results from

Continued on page 66

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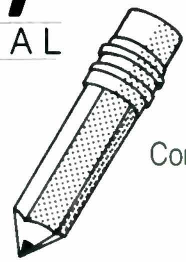

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Subscription Department 9-4 Business Days, Answering Machine, All Other Hours FAX: (603) 924-9467 24 Hours the combined seven reflections involved with the three surfaces nearest a loudspeaker: three reflections involving one surface, three involving two surfaces, and one involving all three surfaces. (*Figure 1*, *SB* 4/92, p. 81, is a view of the full set of the seven image sources [after Harry Olson and former B&W Head of Research, the late Glyn Adams].) I have written "obsessively" on the Allison effect in earlier columns, to which I refer Mr. Roe.

As for Mr. Roe's other points:

Vertical radiation. The deleterious effect on vertical radiation from lower woofer placement presents an interesting problem. I had assumed any company which could execute such unbelievably fine (smooth) work at the upper crossover could solve almost anything similar anywhere else. Second, perhaps a systemic approach could work: turn the 801/802 design into a four-way, with a properly mounted (boundary-close) woofer operating up to 250 or 300Hz, with an upper woofer/lower midrange or some such taking over above it. Or use the B&W bass-EQ component to introduce a variable peak to fill in and smooth out the upper bass and lower midrange.

In any case, my measurements of the vertical radiation pattern of the 802 showed it to be nothing special as is (unlike the spectacular horizontal radiation). See the top curve in *Figs. 2* and *4* in *SB* 5/92, pp. 75-76. Good thing vertical radiation is much less important than horizontal.

Exciting eigentones (resonances), which is preferable to introducing "balancing" dips with highly mounted woofers. Yes, a woofer closer to a boundary has more output than one placed farther away, and so will stimulate (albeit not change) room resonances more. This increase is smooth overall, though, and thus will likely be easier to reduce through broadband crossover padding or other low-Q equalization or tone control.

Equalization. Yes, most forms of digital EQ probably will have better phase behavior than analog EQ (although they probably will not have "no" phase distortion). Fortunately with music we are not sensitive to this either, as any analysis of multiway-loudspeaker phase performance will demonstrate. Analog EQ, long and wrongly damned by the high end, gives fine and euphonious improvements in recording studios (and in other critical listening applications) around the world, and commonly "undoes" phase distortion to boot.

More to the point, the professional audio engineer whose boomy and honky 802s (they were so even half-anechoically, please recall) were the basis for the *SB* 5/92 column is now listening quite happily with his pair—equalized not by the exquisite Sig-Tech digital-EQ system but by an inexpensive analog unit from (gasp) DAK!

Of course, all current crossover design, B&W's and everyone else's, is also a form of analog EQ. And B&W itself also makes that analog bass equalizer for sale with each 801 and 802 series unit, which naturally must introduce phase changes (horrors) of its own.

The B&W bass-EQ component. All I remarked was the B&W manual getting it completely backward: "If the acoustic landscape of your room is unable to satisfactorily absorb low frequencies and produce an acceptable balance, then the use of the B&W Bass Alignment Filter accessory will extend the bass response"—which is just the opposite of what you would wish.

The acknowledged success of the 801 and 802 series speakers is how I began my column. I was baffled at the sonic complaints many owners and fans regularly register about these designs. I heard, measured and documented the problems that accounted for complaints from at least one conscientious B&W owner and fan. I was and am amazed at the company's spectacular midrange-tweeter crossover work and the consequent virtually ideal conventional horizontal radiation pattern. As a reporter of these things I am not partisan, and aim to be neither in nor out of step.

ERRANT PARENTHESIS

There appears to be a missing or extra parenthesis in the formula Robert Bullock provided in "Mailbox," *SB* 5/92 (p. 51):

$$d = [(\omega^2/h - 1)^2 + (\omega/(hQ_L)]^2/h/\omega^8$$

I am also confused by the double denominator (h/ω^8).

Noah Katz
Mountain View, CA 94043

Contributing Editor Robert Bullock replies:

Mr. Katz is right; the correct equation is:

$$d = [(\omega^2/h - 1)^2 + (\omega^2/(Q_L{}^2h))]/\omega^8$$

TUNING DUCTS

I appreciated Howard Mureen's article "Acoustic Resistance-Tuned Enclosure" (*SB* 5/92, p. 10). Some years ago I experimented with resistance loading of bass reflex speaker systems; his article closely follows my experiences. Some points, however, need further discussion.

First, enclosure tuning is determined almost entirely by the distance of the movable panel from the rear panel. This occurs because the volume between the panels becomes a tapered duct for the rear port. For example (as in *Fig. 4*), with a 49 in.² port with a 5⁄16" panel spacing, the entry to the duct is about 25.6 in.² (82 × 5⁄16). The exit of the duct is about 10.2 in.² (32.5 × 5⁄16).

In this and all the other cases he discusses, the exit area of the duct is significantly smaller than the port area. Thus the port has little impact on the tuning, which is consistent with Mr. Mureen's findings. To correctly predict the tuning of this cabinet, you must model the tapered port.

The use of a duct with a high ratio of surface area to volume (which is what exists between a movable panel and the rear panel) is problematic. Such a duct creates a loss which lowers the Q of the bass reflex enclosure, and, as he states, this lowers the peaks of the impedance curve. But this also lowers the sound input from the port.

I would have liked to see frequency response measurements made of the port's near field acoustic output with and without the movable panel. My experience and measurements have shown that by the time you have significantly lowered the Q of the bass reflex, you have significantly lowered the output from the port. I don't think that Mr. Mureen has gone far enough in his design; I suspect that his duct size is still large enough to get significant output from the port.

Dick Crawford
Los Altos, CA 94024

Howard Mureen responds:

I thank Mr. Crawford for his comments. The system is tuned primarily by the tuning panel space regardless of the port area. With an 8" speaker and 36 in.^{2} port, the system was tuned at 43.5Hz. With a 64 in.^{2} port, the system was tuned at 46Hz. With a 12" speaker and 36 in.^{2} port, the system was tuned at 48Hz and a 64 in.^{2} port tuned at 48.5Hz.

The original concept was to pick a box tuned to 80-90Hz, using equations 1 and 2 to determine the size. A speaker was selected with a free cone resonance of about 60Hz. This worked well but introduced some questions; a few were discussed in my article. I'm not sure anyone really knows what happens when you mount a speaker in a Helmholtz resonator. The port size appears to have little effect on tuning. The tapered space (port) between the panels has the greatest effect on tuning my enclosure. As with any experiment, more questions than answers may result.

The final frequency will depend on the driver and the volume of the box. Generally, the larger the V_B/speaker, the lower the final system frequency. I agree that to predict cabinet tuning, you must model the tapered duct. I never intended to equate the box design because it would take longer to calculate than to simply tune the box.

Concerning duct losses, I never noticed any obvious losses nor did I measure the output from the ducts. I did experiment with a smaller panel and box and found that the system could be tuned. The port size also was reduced. Consider as an example: V_B = 1.2 ft.^{3}, 8" Peerless driver, front port 3" in diameter, and a 6" × 6" tuning panel at ½" spacing. This system tuned at 47.5Hz. I later found that the tuning panel could be reduced in size in the 2.55 ft.^{3} test box, which also presents more questions.

FURTHER INVESTIGATION

I am writing to point out an error in *SB* 5/92 (Mailbox, "Quasi Seconds," p. 57). The formula for finding the capacitor value in a "Quasi Second-Order" crossover appeared as C = (To/Z)^2; it should have been C = (To/Z) × 2.

Further investigation of the "Quasi Second-Order" crossover with a zeta of 0.5 shows that its response is based on what Richard Small called a constant-voltage crossover ("Constant-Voltage Network Design," *Loudspeakers: An Anthology*, Vols. 1-25, *JAES*, p. 172). His paper describes second- and third-order versions along with asymmetrical and symmetrical types.

The letter sent in by Dave Degelau ("On SPL Formulas," *SB* 3/92, p. 85) had me reaching for my calculator to check out the Ramsdell Audio 27" driver he mentioned. An advertisement in the same issue gave me:

f_S = 18.5Hz	R_E = 5.7Ω
Q_{TS} = 0.275	L_E = 3.0mH
Q_{ES} = 0.293	X_{MAX} = ±4mm
Q_{MS} = 4.16	V_{AS} = 1,720 liters
N_O = 4.0%	Piston diameter = 23.3"

1,720 liters equals 60.7452 ft.^{3} Using the formula to find eta, (N_O):

$$N_O = (2.7 \times 10^{-8}) \times (f_S{}^3) \times (V_{AS}/Q_{ES}) = 3.544\%$$

Using SPL equals 112 + 10log(N_O), SPL equals 97.5dB.

I agree with Bob Bullock that sensitivity measurement depends on driver placement and room conditions. The Ramsdell advertisement is problematic because it mentions neither. The only conditions stated are "103dB/1W/1m (band-limited pink noise 32–150Hz in 15 ft.^{3} cabinet)," which doesn't tell us much. Most manufacturers use the SPL = 112 + 10log(N_O) formula to determine driver sensitivity. This doesn't predict the room response, but allows us to compare drivers.

Another letter ("Outrageous," *SB* 5/92, p. 64) sent alarms off in my head. Peter Manchev used an OREVOX WC18125 woofer in a box of 2 ft.^{3} with an f_3 of 28Hz and a 1W/1m sensitivity of 98dB. The sensitivity spec sounds far-fetched. Was this an in-room measurement at low frequencies or the manufacturer's measurement at a higher frequency? Some manufacturers will list the spec taken at 1kHz, where larger drivers may have an elevated response. The given parameters are:

f_S = 15Hz
Q_{TS} = 0.444
Q_{ES} = 0.485
Q_{MS} = 5.24
V_{AS} = 9.738 ft.^{3}
$N_O = (2.7 \times 10^{-8}) \times (f_S{}^3) \times (V_{AS}/Q_{ES}) = 0.183\%$
SPL = 112 + 10log(N_O) = 84.624dB

Quite a difference exists (98 − 84.624 = 13.376dB). At any rate, you should use the N_O and SPL formulas to compare apples to apples.

David Long
Dalton, GA 30721

Hi-fi Room

continued from page 43

may be permanently mounted on the wall, or they may be movable. When distributed throughout the room, they have the added benefit of enhancing the room's diffusion.

I decided to use movable modules attached to the wall (*Fig. 10*). Each unit is 2′ × 6′ and houses a 2′ × 2′ Helmholtz resonator to control the lower frequencies. The remaining portion contains insulation for high-frequency absorption.

Off again I went to the home improvement center. I ordered enough wood and other materials to make about five units as a start. I readjusted my radial arm saw, had the blade sharpened, and started to build modules.

Next time in Part III, author Saluzzi provides measurements of his room's performance.

Three-way TL

continued from page 54

fabric to mount the ball. If you use Velcro® for fastening, no drilling will be needed, but you should buy the Velcro intended for cloth. A fabric store is a good place to find this type, if the hardware store doesn't carry it.

85. With thread-locking compound on the screws, remount the speakers. Connect the crossover networks to the speaker terminals and the taps on your amplifier, and play some tunes! Focal drivers take several months to break in, so expect the sound to improve.

ENJOY! We hope the end of this series will be the beginning of many pleasurable hours of project work, followed by years of listening enjoyment. We will be happy to answer your questions, and if you take on the project we'd like to know how it turns out. Send letters to us in care of *SB*. (*Include a stamped, self-addressed business-size envelope, please.—Ed.*)

If transmission lines aren't to your taste, perhaps our comments about crossovers, cabinet construction, hand tools, finishing tips and easy grille frames will be useful to you and find some application in your next speaker project.

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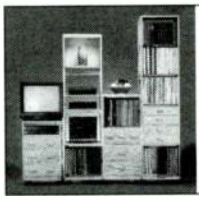

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Distortion analyzers, Heathkit IM5258GC, $100; HP334A, mint condition, $950. Peter Florance, 2700 Virginia Beach, VA 23452, (804) 498-8277.

Bruel and Kjar test equipment, call for list; Dynaco ST-120 amplifier, $100; Van Alstine Super-Pas preamp, $150; AR XA turntable, $45; dbx-118 compander, $45; QED speaker switcher, $20; TOA 30W PA system, $80. Steve, (303) 237-2726, machine (fourth ring).

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Hafler DH-500, new, factory-sealed. Eric, (503) 771-3038.

Hartley subwoofers, model 218HS, diameter 18", bought pair for $880, used less than 100 hours, excellent condition, sell for $500 or B/O. Shinichiro Haruyama, (908) 889-9342.

Apature digital interconnects 1M and 2M, retail $200, $85 both pairs; Phase Linear 4000 Series II preamp, $175; 1000' coax cable, $30; Heath AD1013 audio scope, needs work, $65; Sherwood CD-1000 CD player, never opened, $90. Andy, (414) 458-2057, 5-8 p.m. CST.

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Debra Dahlia speakers, $250/pair; Accuton C2-11, $200/pair; Cabasse DDM4 tweeter, $100/pair; Domiz mid, $100/pair; Focal 6K412L, $150/pair; Marchand crossover two-way, $225; Pass A-40 parts, all parts new and unused. Dan Hildreth, 14100 Meridian Dr. S.E., Everett, WA 98208, (206) 743-1323.

Infinity servo static speakers, $300/pair; Mac225, $700, excellent condition, shipping extra. Brian, (410) 381-5272, evenings/weekends.

EV SM-120 horns, excellent, $175/pair; JBL LE-85 with new Ti diaphragms, large terminals, felt absorbers, factory aligned, $450/pair, with old diaphragms, $350; Community RH-60 horns, 300Hz, $100/pair; B/O or trade. Steve, (203) 397-3888.

Symmetric Sound Systems EQ1 kit, 12-band equalizer, H-P engineer design, metal cover, level-control pots, $45; Shure M68RM four-channel microphone mixer with reverb, looks good, performance unknown, $50 with manual copy; Integrex Dolby-B decoder, never used, $50; prices plus shipping. Andy Keller, 1455 Twinsisters, Longmont, CO 80501, (303) 772-4801.

Garod 50 turntable, fair condition, $25; oak cabinet, 50" × 30" × 19", holds 200 albums and four components, solid wood, no veneer, beautiful construction and finish, B/O, call for details; must pick up in S.E. CT. Walt Fleming, 182 Plain Hill Rd., Norwich, CT 06360, (203) 889-5018.

Hafler DH220 amp, 120W/channel, $250; SAE model 2900 preamp with built in parametric equalizer, $150; Calsod computer-aided speaker design program, $35; all items in mint condition. Nick, (209) 583-6511, PST.

Dynaudio Myrage speakers, excellent condition, $3,200 or B/O per pair; electronic crossover Madisound Sledgehammer, mint, $275. Paul, (805) 640-0844.

Nice walnut speaker cabinets, I.D. 22½" × 14½" × 9⅛", 8" speaker cutout, black grilles, $80/pair; Polydax MTX20X25 R5N 8Ω2CN12, 8" TPX cone, magnesium cast frame speakers $60/pair; Realistic 2" × 6" #40-1379 horn, piezo tweeters, $20/pair. Jerry Feldstein, 705 E. 189 St., Bronx, NY 10458, (718) 364-3485, 7-10 p.m. EST, no machine.

JBL D-123 12" woofers, $125/pair; 2334 100° horns with 175 Alnico drivers, $450/pair; pro speakers: JBL control 10 monitors, three-way, 12" woofer, $650/pair; Altec 604 coaxials, ferrite, Mantaray horn, $550/pair; preamps: Kenwood C-500, $180; SAE MK30 rackmount, $100; Eumig C-1000 rackmount, $175. David, (914) 688-5024.

Pair Vieta L100Y woofers; (1) Focal 10V516; (2) Tonegen 16K65; (2) Tonegen 94C70; pair 24" speaker stands; (1) preamp/tuner; (1) NAD or Nakamichi stasis basic stereo amp. Jim, (708) 425-6719.

Frequency counters; Hewlett-Packard, General Radio, both accurate to three figures below 100Hz, $100/each; (3) rackmount power supplies: Spectra Sonics 402RS ±25V at 6A, $15/each; pair Altec 808-8A drivers, new diaphragms, $125; Bose 402-E active equalizer, $25; all plus shipping. Andy, (303) 781-5573.

General Radio audio graphic level recorder, $75; many SAMS tape recorder and transister radio manuals, $5/each; Hewlett-Packard 400H AC VTVM, $45; send SASE for list of other goodies. Richard Honeycutt, 122 Olivia Dr., Lexington, NC 27292, (704) 249-3526 after 5 p.m. EST.

Toroidal transformers: 48VCT, 8A, 384VA, $25; caps: 250W VDC, 8,800 MFD, $15; isolation transformers: 1KVA, 120VAC, $100. Harold, (716) 624-9159.

B+K EX-442 Sonata 200W amp, excellent condition, $725; DC-coupled, gold inputs & outputs, same predriver and power MOSFETs as B+Ks highly acclaimed monos; (4) Morel MW224-8s, unused, $100/pair; (2) Morel MDT33s, $50/pair, need voice coils; (1) Pyle 6½" woofer, $35; will pay shipping. Art, (410) 583-8293.

WANTED

Source of Philips TDA1520 or TDA1514 (preferred) amplifier ICs needed (see *Speaker Builder*, 1/92, page 72). Write Wally Kowalski, 5811 110th Ave. N.E., Kirkland, WA 98033 or Email on Compuserve at 70544,52.

Manuals, schematics and modifications for Scott #299 integrated amp; Scott #130 preamp (need power transformer #TR-5 500VCT, 25V, 6.3V); Fisher #100 50W tube amp; FM1 multiplex board; Eico ST-120 tube amp. Will pay postage/copying cost. Ian Baren, PO Box 541, Katonah, NY 10536, (914) 763-5659, FAX (914) 232-0773.

Would like to find source for replacement Decca ribbon tweeter diaphragms. If you have two or info, please contact Ron Goldberg, 1195 St. Vincent Dr., Monroeville, PA 15146, (412) 373-3118.

Dyna ST-35, MK-III, SCA-35, MK-II, ST-70 and MK-IV working units or related parts (ie. chassis, power/output transformers, cages, quad capacitors, etc.) Also, Dynaco-related tubes by (ie. Mullard, Sylvania, GE, Philips: EL-34/6CA7, 7Z47, 6550A, 5AR4, etc.), mint condition; McIntosh MC-30, MC-40 monoblocks or MR-71 tuner. Marc, (609) 848-9074.

Look for JBL 2123H, 2105, 2403, LE-5, LE5-2, 2202, LE8T 16Ω horn, 2397; also, Lowther PM4A, PM5A, PM2A and TPI enclosure; Focal tweeters FC120; Dynaudio D21. Rudy, (813) 441-2883.

Yamaha T-80 tuner. Philip, (602) 744-3526.

Old Klipsch catalogs, manuals, crossover components; old JBL catalogs, literature; books: Shockley, *Electrons and Holes in Semicounductors*, R.C. Schaller, *Throne of Merlin*; Altec N500D crossover; Marantz 7T with case. D.R. Schaller, 6704 Schroeder Rd., Suite 6, Madison, WI 53711.

CLUBS

TUBE AUDIO ENTHUSIASTS. Northern California club meets every other month. For next meeting announcement send a self-addressed, stamped #10 envelope to Tim Eding, PO Box 611662, San Jose, CA 95161.

THE WESTERN NEW YORK Audio Society is an active, long established club located in the Buffalo area. We issue a newsletter and hold meetings the first Tuesday of every month. Our meetings attract many prominent manufacturers of audio related equipment. We are involved in all facets of audio—from building/modifying to exposure to the newest high-end gear, and the chance to hear more types of music. For information regarding our society, please write to WNY Audio Society, PO Box 312, N. Tonawanda, NY 14120.

WASHINGTON AREA AUDIO SOCIETY Meetings are held every two weeks, on Fridays from 19:00 hours to 21:30 hours at the Charles Barrett Elementary School in the city of Alexandria, Va. Prospective members are welcome but must register in advance in order to be admitted to the meetings. No exceptions please. If interested please call Horace Vignale, (703) 578-4929.

THE CATSKILL AND ADIRONDACK AUDIO SOCIETY invites you to our informal meeting. Join our friendly group of audio enthusiasts as we discuss life, the universe and everything! Toobers, Tranzeestors, vinyl canyons or digital dots. No matter what your level of interest, experience, or preferences, you are welcome. Contact CAAS at (518) 756-9894 (leave message), or write CAAS, PO Box 144, Hannacroix, NY 12087. See you soon!

CONNECTICUT AUDIO SOCIETY is an active and growing club with activities covering many facets of audio—including construction, subjective testing, and tours of local manufacturers. New members are always welcome. For a copy of our current newsletter and an invitation to our next meeting, write to: Richard Thompson, 129 Newgate Rd., E. Granby, CT 06026, (203) 653-7873.

ELECTROSTATIC LOUDSPEAKER USERS GROUP is now a world-wide network for those interested in sharing valuable theory, design, construction, and parts source information. If you are interested in building, or have built, your own SOTA ESL we invite you to join our loose-knit organization. For information, send a SASE to: Barry Waldron, 1847 Country Club Dr., Placerville, CA 95667.

LONDON LIVE D.I.Y. HI-FI CIRCLE meets quarterly in London, England. Our overall agenda is a broad one, having anything to do with any aspect of audio design and construction. We welcome everyone, from novice to expert. For information contact Brian Stenning, 081-748-7489.

THOSE INTERESTED IN AUDIO and speaker building in the Knoxville-East Tennessee area please contact Bob Wright, 7344 Toxaway Dr., Knoxville, TN 37909-2452, (615) 691-1668 after 6 p.m.

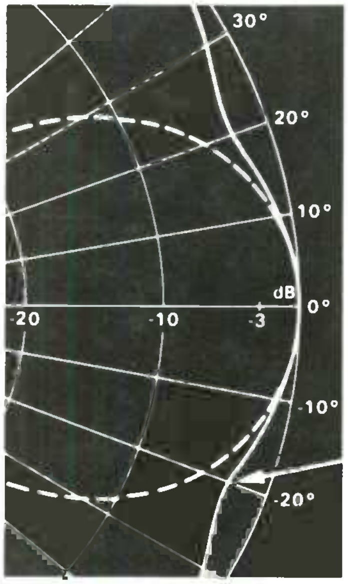
AUDIOPHILES IN THE DAYTON/SPRINGFIELD, OHIO AREA: We are forming an audio club. Please contact me if you're interested in construction, modifications, testing, recording or just plain listening to music. Ken Beers, 1756 Hilt Rd., Yellow Springs, OH 45387, (513) 767-1457.

ARIZONA AUDIOPHILE SOCIETY Located in Metropolitan Phoenix is a growing and active club in the pursuit and reproduction of recorded music. New members are welcome. Meetings are last Tuesday of each month. Receive monthly newsletter and biannual journal. Club discounts with local high-end audio dealers. Send inquiry to Arizona Audiophile Society, PO Box 13058, Scottsdale, AZ 85267, or call Bob Williams, (602) 944-5929.

AUDIO SOCIETY OF MINNESOTA Now in its 15th consecutive year! Serving the many and varied interests of audiophiles in the upper midwest. Monthly meetings, tours, audiophile concerts, special guests. For information and a sample of our latest newsletter, write ASM, PO Box 32293, Fridley, MN 55432 or call our 24 hour "Audio Hotline," (612) 825-6806.

THE ATLANTA AUDIO SOCIETY is dedicated to furnishing pleasure and education for people with a common interest in fine music and audio equipment. Monthly meetings often feature guest speakers from the audio manufacturing and recording industry. Members receive a monthly newsletter. Call: Chuck Bruce, (404) 876-5659, or Eddie Carter, (404) 847-9296, or write: A.A.S., 4266 Roswell Rd. N.E., K-4, Atlanta, GA 30342-3738.

THE BOSTON AUDIO SOCIETY the nation's oldest (founded 1972), seeks new members. Dues includes the monthly meeting notice and our newsletter, the *BAS Speaker* (6 times/year). Recent issues cover Carver, a/d/s; the founder of Tech Hi-Fi; Photo CD; plus visits from famous speaker designers; listening tests; measurement clinics; research investigations; and more. Back volumes available. Membership includes engineers, journalists, consultants, and music-loving audiophiles like yourself. For information write to PO Box 211, Boston, MA 02126-0002, USA.



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THE INLAND EMPIRE AUDIO SOCIETY (soon to become) **THE SOUTHERN CALIFORNIA AUDIO SOCIETY—SCAS** is now inviting audiophiles from all areas of Southern California and abroad to join our serious pursuit for that elusive sonic truth through our meetings and the **IEAS'** official speaker, *The Reference* Newsletter. For information write or call, Frank Manrique, President, 1219 Fulbright Ave., Redlands, CA 92373. (714) 793-9209.

IF YOU ARE an "Organ Music Lover" and like to test your audio system, **SFORZANDO** has room for a few more members. We have about three thousand "Live," on-the-spot, cassette tapes that are not available in the stores. We are happy to lend them to you via the mail. Just ask EA Rawlings, 5411 Bocage St., Montreal, Canada, H4J 1A2.

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, design analyses, digital audio, A-B listening tests, equipment clinics, recording studio visits, and audio fun. The club journal is *LC, The SMWTMS Network*. Corresponding member's subscription available. Call (313) 544-8453 or write David Carlstrom, SMWTMS, PO Box 721464, Berkley, MI 48072-0464.

MEMPHIS AREA AUDIO SOCIETY being formed. Serious audiophiles contact J.J. McBride, 8182 Wind Valley Cove, Memphis, TN 38125, (901) 756-6831.

NEW JERSEY AUDIO SOCIETY meets monthly. Emphasis is on construction and modification of electronics and speakers. Dues includes monthly newsletter with high-end news, construction articles, analysis of commercial circuits, etc. Meetings are devoted to listening to records and CDs, comparing and A-B-ing equipment. New members welcome. Contact Frank J. Alles, (908) 424-0463, 209 Second St., Middlesex, NJ 08846; or contact Bob Young, (908) 381-6269, or Bob Clark, (908) 647-0194.

PACIFICNORTHWEST AUDIO SOCIETY (PAS) consists of 60 audio enthusiasts meeting monthly, second Wednesdays, 7:30 to 9:30 p.m. at 4545 Island Crest Way, Mercer Island, Washington. Be our guest, write Box 435, Mercer Island, WA 98040 or call Bob McDonald, (206) 232-8130 or Nick Daniggelis, (206) 323-6196.

PIEDMONT AUDIO SOCIETY Audio club in the Raleigh-Durham-Chapel Hill area is meeting monthly to listen to music, demonstrate owner-built and modified equipment, and exchange views and ideas on electronics and speaker construction. Tube and solid state electronics are of interest and all levels of experience are welcome. Kevin Carter, 1004 Olive Chapel Rd., Apex, NC 27502, (919) 387-0911.

THE COLORADO AUDIO SOCIETY is a group of audio enthusiasts dedicated to the pursuit of music and audiophile arts in the Rocky Mountain region. We offer a comprehensive annual journal, five bi-monthly newsletters, plus participation in meetings and lectures. For more information, send SASE to: CAS, 11685 W 22nd St., Lakewood, CO 80215, (303) 231-9978.

THE HI-FI CLUB of Cape Town in South Africa sends a monthly-newsletter to its members and world-wide subscribers. To receive an evaluation copy of our current newsletter, write to: PO Box 18262, Wynberg 7824, South Africa. We'll be very pleased to hear from you.

THE PRAIRIE STATE AUDIO CONSTRUCTION SOCIETY. (PSACS) meets every other month. Meetings feature audio construction, design, and analyses, blind listening tests, equipment clinics, autosound, lectures from manufacturers and reviewers. PSACS, PO Box 482, Cary, IL 60013, call Tom, (708) 248-3377 days, (708) 516-0170 eves.

HI-FI COLLECTOR/HOBBYIST seeks "living letters"/audio penpals from other states to correspond via reel-to-reel tape. Non-commercial strictly; make up short monologues on subjects from vintage technology, with regional FM excerpts for background or equipment samples, from personal tales of yard sales scavaging success, repair/restoration tactics and strategies, favorite service centers, general ways to handle the burgeoning obsession with arcane hi-fi gear. All correspondence on 3", 5", 7" reels (¼" tape) will be cheerfully answered and tapes returned via parcel post. James Addison, 171 Hartford Rd., Apt. #7, New Britain, CT 06053.

MONTREAL AREA SPEAKER BUILDER looking for others interested in speaker design and construction from small to large systems. Feeling like I'm the only one. Prove me wrong! Andrew McCree, 4701 Jeanne Mance, Montreal, Quebec H3V 4J5, Canada, (514) 281-7954.

SPEAKER BUILDERS/AUDIOPHILES in the Milwaukee, WI area. I am a speaker builder with test gear looking to join or form an audio club. Anyone interested contact, Kirk Rontti, (414) 355-7509 leave message.

LOS ANGELES AREA ARIA AND SWAN Loudspeakers Users Group. If you have built or plan to build any of the Aria or Swan loudspeakers and would like to meet for listening sessions or have any questions or modifications that you would like to share, please call Geoffrey, (213) 965-9173 or Edward, (310) 395-5196.

GREAT BASIN AUDIO SOCIETY. A club for those interested in better recording and reproduction of music, who live in Northern Nevada and surrounding parts of California, Idaho and Utah. Everyone is welcome to come to our monthly meetings, held in Reno on the last Sunday of each month. We also seek contributions to our quarterly newsletter, *The Singing Sagebrush*. For more info, contact the GBAS, c/o E.A. Barbour, 552 N. McCarran, #284, Sparks, NV 89431 or leave a message on (702) 358-2019.

Advertising Index

Moran in the Market

IN THE PINK OF THINGS

By David R. Moran

The Old-Fashioned Way

As a loudspeaker audio test signal, pink noise is pretty badly out of fashion these days—hopelessly square—and real-time analysis thereof is even more so. At last fall's AES convention in San Francisco, I am told, a loudspeaker-measurements workshop did not even include the technique. But with a continuously averaging ⅓-octave real-time analyzer (although few have that capability), it remains immensely reliable for simple spectral judgments.

If you have the opportunity and the willingness to work outside, moreover in a half-space (2 pi) environment, you can get quite revealing and useful half-anechoic data too, as I've tried to show in these pages for the last year and a half with the dbx RTA-1 (now the SoundTech RT4000). You must be willing to accept ⅓-octave resolution, which is not the limitation some claim, and worse, if you are using a typical handheld RTA, without continuous averaging, you must also become expert at squinting to "eye-average" its bouncing readout, in order to make worthwhile judgments about the lower midrange and bass regions.

Ivies, with very effective slow LED movement possible at the highest dB/div setting, and with steep filters as well, are considered by expert users to be pretty good (i.e., useful) in this respect. Audio Controls and others like them, with jumpy LEDs regardless of setting and with less-steep filters, are thought to be much less so. As a quick test of any RTA's usability and accuracy, simply close-mike a sealed-box woofer's response to pink noise, and look at how much the display shows that nice textbook 12dB/octave rolloff below the given corner frequency, like so many of the theoretical graphs in this publication. Or just feed flat pink noise into the unit and see how flat and smooth the top of the display bands lie. The ability to store responses in memory, even when they're brief and inaccurate snapshots, and then average them is nice in an RTA, as is printing capability, but that's another subject.

Of course, for any RTA to work at its best, it's essential that the pink noise employed be precisely flat (flat-topped), meaning that it must average to flatness—to the same amplitude level in each band—within a certain number of seconds or samples, and not too many seconds or samples. Now wait a minute, I hear you mutter, did he just say "flat pink noise"? Pink noise is flat, and flat-looking, by definition, you continue: it's white noise—equal energy per frequency, producing a rising amplitude response—put through a −3dB/octave pinking filter to achieve straight-topped audioband frequency response, with equal energy per octave or any subdivision thereof. Oh sure, maybe the pink noise generated by a cheap mail-order equalizer is not ruler-flat. But CD players are, even portable ones, and so would be test CDs. Indeed, that combination these days gives everyone cheap, high-quality, extensive signal-generation capability which was unimaginable (and/or costly) less than a decade ago.

Testing, Testing

So okay: *do* test CDs have flat pink noise? To see if the common wisdom held concerning this quaint test signal, I recently measured numerous CDs containing same. I used my trusty dbx RTA-1, which in less than a minute can measure its own unsurpassedly flat pink noise to within ±0.2 or ±0.3dB across the full audio band. To play the test discs I turned to a CD player which a sinewave sweep showed to be flat to less than ±0.1dB. I was lent the compact discs by DB Systems, of Rindge Center, New Hampshire, whose proprietor, the estimable audio engineer David Hadaway, stocks virtually every test CD ever made, among a variety of other audio and electronic offerings. Our project's goal was to assess all CDs with pink noise on them, although we've probably missed a few (for example, *The Digital Domain*, Elektra 9-60303-2, according to Bert Whyte in the November *Audio* magazine).

As so often happens in audio when you get down to actually measuring something, the results were sometimes startling in their imperfection—especially since most of these CDs' liner notes go on about how precisely and carefully they and all their signals were created and assembled. Admittedly, for almost all p/n measurement situations, small imperfections will not matter a whit, and the larger, 1–2dB deviations exhibited by the four Denon-based CDs, the two *Stereophile* CDs, and the B&K and Philips CDs would matter only if you were using a high-precision machine with continuous averaging. The Ultimate (uh-huh) CD is alone in having its p/n fail utterly, and miserably.

Also, keep in mind that whenever the pink noise comes within ±0.3 to ±0.5dB in flatness across the band, it has approached the resolution of the dbx RTA-1 itself, especially when the cut lasts less than a half-minute. Still, however trivial in the big scheme of things most of the non-flat performance is, realize that phono cartridges—you remember them, don't you?—commonly showed better smoothness across the band than many of these test CDs.

More significant, with some of those ultra-prestigious corporate names, you gotta wonder why nobody ever bothered to look at the pink-noise generator's output. I mean, we're (choose one: Philips, B&K, Denon...), so we don't have to check? It naturally causes one to fret about the rest of the signals on, and the actual effort that went into, each company's flagship test CD.

Since white-noise generators are not difficult to get precisely right, the quality of pink noise tends to depend on the pinking filter. Nothing in electronics naturally falls at 3dB/octave, so the filter must be a −6dB/octave design with flattening-out stages to achieve the desired −3dB/octave rolloff. The more such stages, and the more extensive the design and the parts, the more perfect the filter: six or more poles and zeros, 1% or better resistors and 5% or better capacitors, and so on. Many of the pinking filters used for these CDs, obviously, are not exact enough for precision testing.

The unequivocal loser of the entire batch was the *Total CD Test Disc Sampler TRCD 900*, which I was kindly lent by audio consultant/journalist E. Brad Meyer, of Point One Audio (also my Lincoln, MA, neighbor). On this truly strange CD, following a baker's dozen jet flybys, some with muted sonic boom; then a weird assortment of car alarms; a faked (synthesized) rocket launch; "alien battle" and "laser battle" medleys; cartoon-UFO and spacecraft sounds; and a time warp, all capped off with a rap instrumental—I am not making this up—comes a set of pink-noise cuts at various levels. Trouble is, the noise is not pink, it's white! Someone evidently forgot to click the filter knob to the proper position on the generator. So Total is, like, totally disqualified.

In the Details

All of the pink-noise curves shown here, then, are the genuine thing, and represent an average of a few passes of continuous averaging of the entire pink-noise cut, which, depending on the individual CD, may be quite long, or uselessly short: less than 10–15 seconds. All the passes were quite close, within tenths of a decibel. A handful of these test CDs gives you two channels of pink noise (p/n) that are *uncorrelated*, or "stereo," which with multiple-loudspeaker setups yields more realistically accurate measurements (and much more flattering curves below 150–300Hz). These stereo-p/n CDs are so indicated, and for their graphs, the two channels were themselves averaged, but again they always matched. For assessing a single loudspeaker, of course, mono-p/n test CDs are just as good, and along with a single stereo-p/n disc were the winners for flatness.

The curves shown here are plotted only to 16kHz. The CD recording chain is sharply low-passed above 20kHz and a ⅓-octave RTA does not get to see the full ⅓-octave centered on 20kHz (it extends almost to 22.5kHz), so on its display it misleadingly rolls off the curve above 16kHz. Also note the greatly expanded vertical scale, 1dB/division. Levels are actual dBV: decibels below 1V. (I should add that, at the other end, I do not know how low below 20Hz these CDs' pink-noise samples reach. CD players themselves commonly have extended infrasonic response, and vented systems among others will not like being asked to cope with full-level 5–10Hz noise. Unfortunately, the dbx RTA-1's p/n output is flat all the way down to a few hertz, a truly nutty and potentially dangerous piece of design.)

Pricing information for a given test CD of interest to you is best gotten from Old Colony Sound Lab or DB Systems (addresses and phones at the end of the column) or a similar mail-order service, or from your local audio-specialty dealer. So are full details of which test CDs contain precisely which signals—for when you need to know exactly where to find a given cosine, Hamming window, impulse, toneburst, bandlimited or filtered noise, or sweep speed.

Please note that almost all of these CDs have moments that are *extremely* dangerous for your tweeters, and quite possibly your hearing. High-level tones commonly come on with no, or too little, warning! Don't listen to *any* test CD you choose without being right next to the volume control, or holding the remote. Better, preview it with headphones, boring as that may be. The test signals tend to be annoying, so warn your domicile's other occupants, including your pets.

Herewith are cursory notes on my findings, including occasional and miscellaneous comments on other interesting aspects of the CDs' contents. I give them here because pink noise is, you know, only so interesting all by itself.

The *Carver CD4000*, which I regularly use for my *SB* reviews, contains a full minute of stereo p/n of reasonable, if not exemplary, flatness. It otherwise features pleasant jazz and assorted signals for demonstrating and adjusting Carver Sonic Holography circuits, and, being promotional, a fair amount of spoken product hype. This CD is somewhat unusual in having lengthy tones below 20Hz.

The *NAB Broadcast and Audio System Test CD* sets a professional, rarely met standard of execution in the enormous range of broadcast-measurement signals it contains and in its crisp, well-written, thorough notes. (Laziness and sloppiness, not to mention typos and not-quite-right casual technical English, characterize much of the notes of other companies' test CDs.) The NAB CD's minute of pink noise, half mono and half stereo, is reasonably flat if not outstanding. Overall, this CD will be of little interest to the engineer or audiophile who does not work at a radio or TV station, but that's hardly surprising.

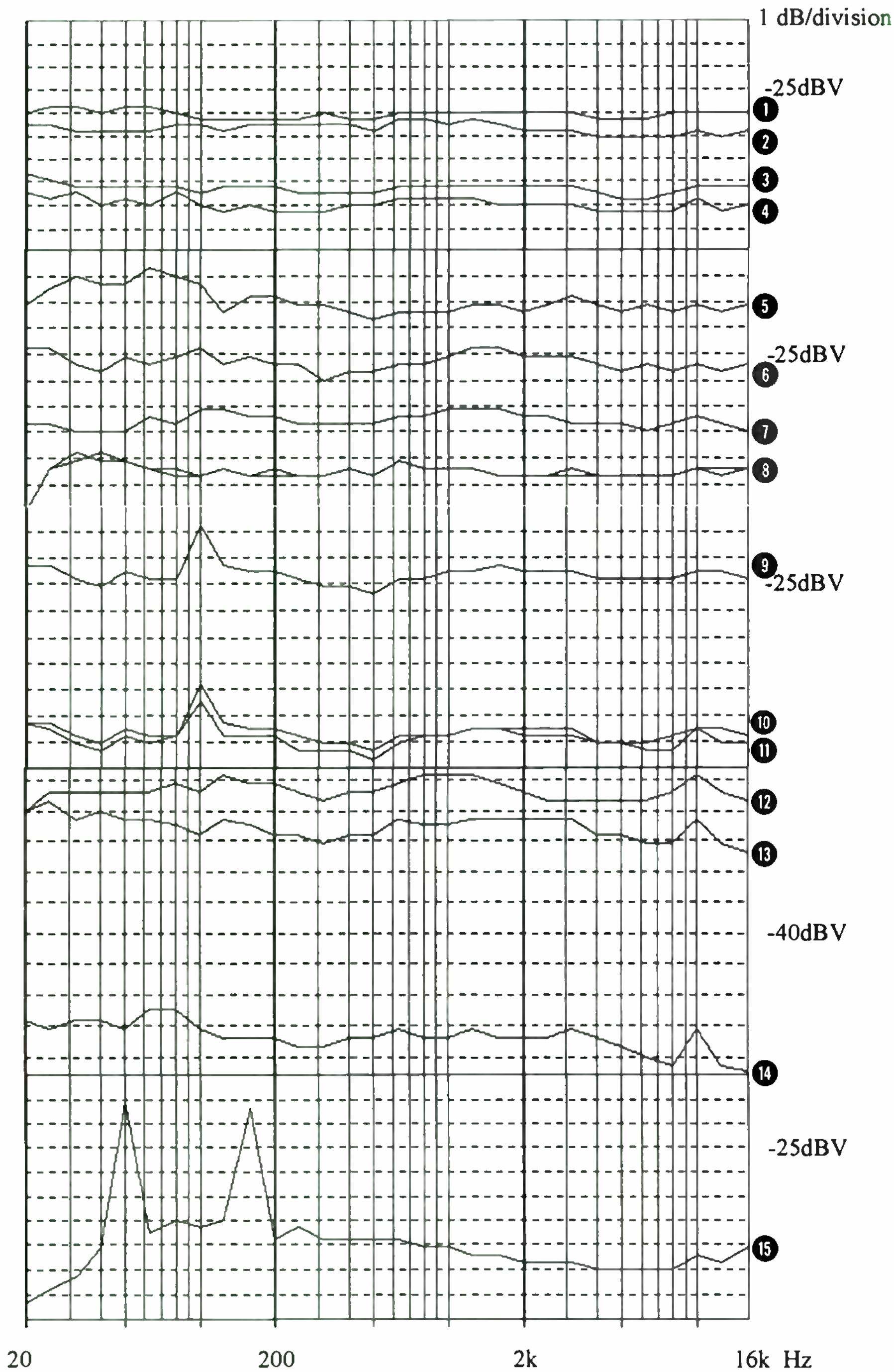

FIGURE 1: From top, pink-noise curves of the JAS/JACA (Victor) **1**, Pierre Verany **2**, JAS/EIAJ (Sony) **3**, and ProSonus test CDs **4**; then B&K **5**, NAB **6**, Carver **7**, and *Stereophile* 1 and 2 **8**, then the two identical-p/n Denon test CDs **9**, represented by one curve, and the similar two *HFN/RR* CDs **10**, **11**, all with a 100Hz bump; then Staccato **12** and Staccato 2 **13**, and Philips **14**; and finally, at bottom, the Ultimate test CD **15**. See text for details and full catalog numbers. Note the expanded, 1dB/div scale, with all levels being dBV.

Denon's famous "anechoic-orchestra" CD, PG6006, contains just under a half-minute of pink noise, flawed by a 2dB spike at 100Hz, probably a harmonic of the 50Hz AC line frequency. Otherwise, the CD is musically and sonically most interesting, with a wide range of classical samples, including an orchestra playing in an extremely dead environment (but hardly full-band anechoic, as claimed). Also featured are mixing and miking comparisons; fair, albeit crude simulations of famous-hall acoustics (Boston's Symphony Hall is recognizable); singling out of various instruments and choirs in an orchestra; and much much more, including a very wide range of test signals. You may actually tire of Mozart's *Marriage of Figaro Overture*. The notes put forth goofiness like (a propos miking) "the wrong environment can have a drastic effect."

The *Denon Audio Test CD 38C39-7147* has the same pink noise as the above Denon CD, with the same 100Hz-peak problem. Otherwise it has the full range of signals, mostly for testing CD players, along with another nice range of music, mostly classical, all fine-sounding, all analog (!). One good idea for assessing any D/A-converter problems is orchestral and then piano cuts at −60dB; at the least you will be able to hear how noisy your system gets with excessive, mis-scaled gain. Elsewhere, an IMD test goes dangerously to 0dB without warning, after you've been lulled by minutes of −15 and −20dB signals. The 50-second sweeps sounded grungy to me.

The two *Hi-Fi News & Record Review test CDs, 003 and 015 (HFNII)*, both got their flawed, 100Hz-peaked pink noise from Denon, too, although some half-decibel ripple crept in along the way to the UK, or at least between UK productions. Otherwise these discs are pretty neat, and overflowing with diverse sounds intriguing and gratifying alike.

On the second CD, some musical material also is borrowed from Denon (quasi-anechoic Mozart, interesting mike-pickup comparisons); other material ranges from *Miami Vice* soundalikes through Sousa to wide-ranging classical, much of it recorded Ambisonically, which I greatly like. (Nimbus helped the production.) A rock-mix assembly tutorial will prove enlightening. Tweaky bias ruins an already rigged comparison (Handel's wondrous Queen of Sheba arrival music, from *Solomon*, in two very different performances—a drawback in itself) of "valve" and transistor mikes. The confusing liner notes are blatantly prejudiced in the matter; worse, and compounding the unfair-

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ness, the condemned version is loud and bright and fast, while the sanctified tube version is slower, more nicely and warmly balanced tonally—and 2dB or so quieter!

Big Ben tolling on HFN/RR II isn't much to thrill to, whereas on the first HFN/RR disc the drolly announced (as unintentional Monty Python), unbelievably powerful garage-door closings that demonstrate the Dynamic Range of Real Life remains about the coolest thing ever recorded on CD. One of the Great Moments in Audio, it is a tremendous amp-clipping test. Comprehensive sets of tones and other CDP and loudspeaker test signals (including infrasonic ones) complete the fare.

The two *Stereophile test CDs (STPH-002-2 and 004-2)* are, like the HFN/RR discs, chockablock with interesting and useful sounds, the nontest ones generally being longer, more classical and subdued (even boring, just as a lot of serious, intent, comparative listening is) than the thunder of machines or nature on other discs. The pink noise comes in generous mono and stereo helpings, around a minute each, and is of outstanding flatness except for an unfortunate rolloff below 25Hz. (You have to wonder how that came to pass.) A range of useful and unusual test signals is included, some possibly even dubious.

Elsewhere, you get to hear vanishingly subtle digital-converter and other musical comparisons, and, as staffers and friends contribute, myriad mikes and microphony technique (demonstrated with J. Gordon Holt reading); natural barks; decent pianism; historical Holt tapes; awesome bass from editor John Atkinson (come to think of it, he *does* look like one of the Animals—you don't suppose . . .); a plausible Jimi Hendrix paean from that sensationally, read-out-loud funny writer Corey Greenberg (the Dave Barry of audio); and the unlistenably fruity tones of Lesley (Mrs. Dick) Olsher, whose overripe pipes are employed by some of the magazine's staffers as test listening material. But I must say, it is nice to see people in audio make music. As with the HFN/RR discs, again, much more also is worth one's attention.

The *Japan Audio Society has test CD-1 (YDDS-2)*, produced with the EIAJ and Sony. Subjectively clearer and cleaner than some of the others, it features an abundance of really useful, almost imaginative tones and sweeps: unusual weighted noise; dangerous unannounced level jumps to IMD tests; timid, low-passed-sounding starter's pistol shots in an anechoic chamber; and bursts of filtered noise ascending into the treble, good for checking your hearing at low levels. I had great difficulty hearing very quiet 12.5kHz-centered noise; my same-age wife, in another room, answered, "Are you kidding? Sure I can hear that."

No music or natural sounds are present on this disc. Its pink noise is extremely flat, in several samples, from five seconds to two minutes (whatever would you use p/n of that length for?).

Also from the Japan Audio Society (with the Japan Acoustical Consultants Association and the Victor Company of Japan) comes *Test CD PRCD-1012*, with a huge range of test signals, again including noise of various spectra. There are more warning beeps before the dangerous stuff than usual, thank you. Also an odd melange of funky, unpretentious, almost touching Japanese instrumentals and vocals, from drum to pop, from ceremonial and religious to jazz and Western classical, along with the usual jets and cars. One puzzlement is some odd other-channel clicks during single-channel tests. This disc's half-minute of stereo pink noise is also a winner, maybe the most nearly flat of the entire batch; would that it were longer.

The *B&K Pro Audio CD4090*, a promo disc for the company's fabulous 4000-series mikes, mostly is various musical cuts (with levels jarringly all over the place), some of them quite fine and fine-sounding. It is handy to have so many genres in one place. The brief pink noise is slightly bassy, which is odd (there is out-of-phase pink noise, which is odd in a different way). The booklet is kind of slapdash, too, with funky proofreading and punctuation and grammar, but then there seems to be some buzzing distortion on the disc as well. Altogether, not quite what you'd expect from B&K.

Also widely reviewed is the French *Pierre Verany/Diapason magazine Compact Test/Demonstrations (PV.784031)*, which, with two other PVs, is sort of the grandfather of the CD-test genre. From musique ancienne (13th century) to Indian harp to romantic organ to steam trains we go, and thence to Gallic tones for speaker and system testing, and noise of which the pink is very flat.

The US *ProSonus Studio Reference Disc SRD* is another remarkably thorough, comprehensive set of professional test signals with a bibliography and other extensive but somewhat weak documentation—neither pink noise nor the pinking filter "approximates the human hearing system's response curve." Several of these test CDs also say something similar, so I guess they are talking about logarithmic, or constant-percentage, bands.

The minute of pink noise is extremely flat, another winner. Otherwise it's a mixed bag: the usual high- and lower-level tones and full-band sweeps, bursts and impulses; rather more novel are reverb-time tests, TEF sweeps, pitch references that will seriously mislead because they're sawtoothed, meaning their *loud* harmonics practically swamp the fundamental pitch, and the puzzling maracas-shaker-sounding LEDR loudspeaker image-height test (also appearing on a few other CDs). The bunch of piano samples includes a nice 88-note scale (not an "arpeggio," as the announcer has it) and octave of pitches, but this ProSonus venture is concluded with a truly awful-sounding piano excerpt in an ugly bit of miking.

The venerable *Philips Test Sample 3 410 055-2* is another extensive set of test signals, mostly for CD player assessment, of course. The lengthy pink noise is mediocre as to flatness, falling more than 2dB from 20Hz–20kHz, with its level lower than anyone else's by some 5dB, also.

From Germany's *Audio* magazine come the two *Staccato CD Sound Samplers (CD 101003 and CD 101013)*, which contain an amazing assemblage of natural sounds and in some ways are the most fun of all of these CDs. Disc 1 features an ear-catching range of wind instruments; a fluttery piano; a listed and annotated Bach Toccata and Fugue (the youthful rock 'n' roll one in d which everybody knows, S.565) but in fact missing the fugue; astonishing glassbreaking; evocative ringing phones of different countries and decades; and wonderful birds, cars, trains, planes, snoring, etc.

Staccato 2 is even more engaging for being largely binaural, making for uncanny headphone listening. It contains ensemble music (large and small, classical and non-, and including dulcimer, brass and marching bands, and plausible Dixieland); superb animals (try those cuts on your children and pets); a virtual history of transportation; drills (including dental); popping champagne corks; and whatnot. None of the pink noise is particularly distinguished, although it's acceptable enough, and ample: the first disc gives us 45 seconds of stereo p/n, and the second has half-minutes of mono p/n with and without preemphasis, of stereo p/n, and of out-of-phase p/n (the usefulness of which I am still trying to figure out).

Finally, inferrably from Germany, too, is the *Ultimate Test CD* (WMCD 1112)—uncharming, reckless, and so dangerous as to begin with 10 minutes (yes, 10 mintes) of an unannounced 0dB-level 1kHz tone, or sinus, as they term it. Many more tones follow, along with fast sweeps, SMPTE code, drum solos, and surely the worst pink noise ever produced or recorded: rougher than ±1.5dB even without two gross line-frequency-related 6dB spikes, at 50 and 150Hz.

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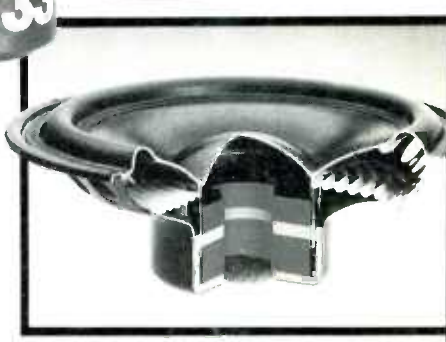

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